Volume 29 DECEMBER, 1945 Number 12

BULLETIN
of the
American Association *of* Petroleum Geologists

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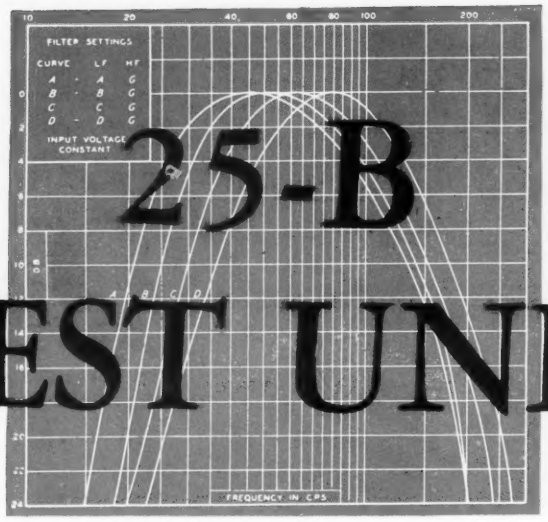

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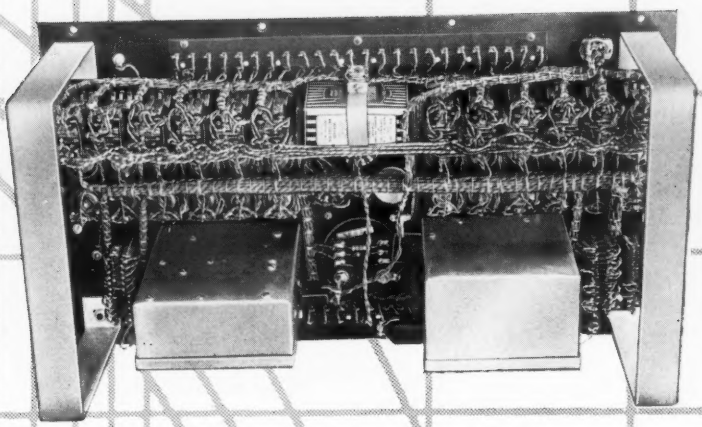

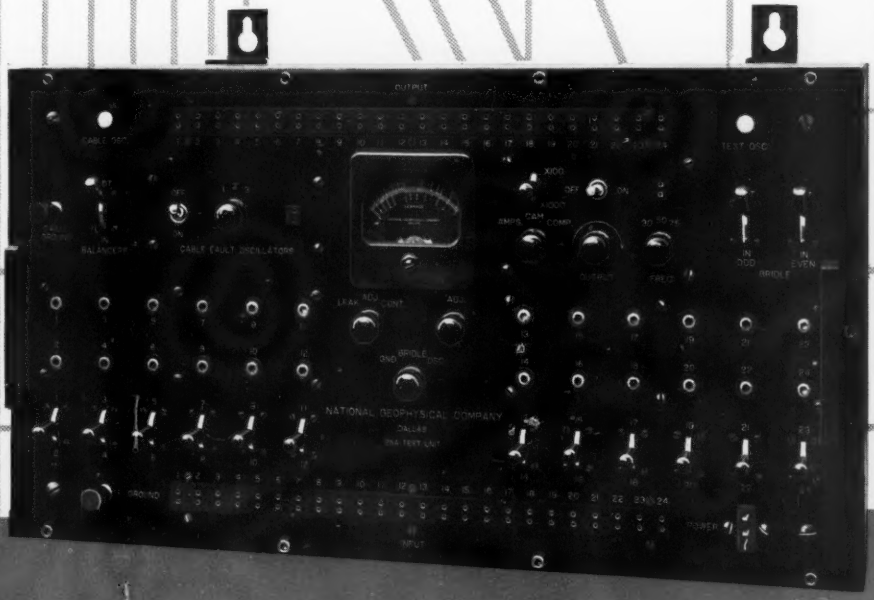

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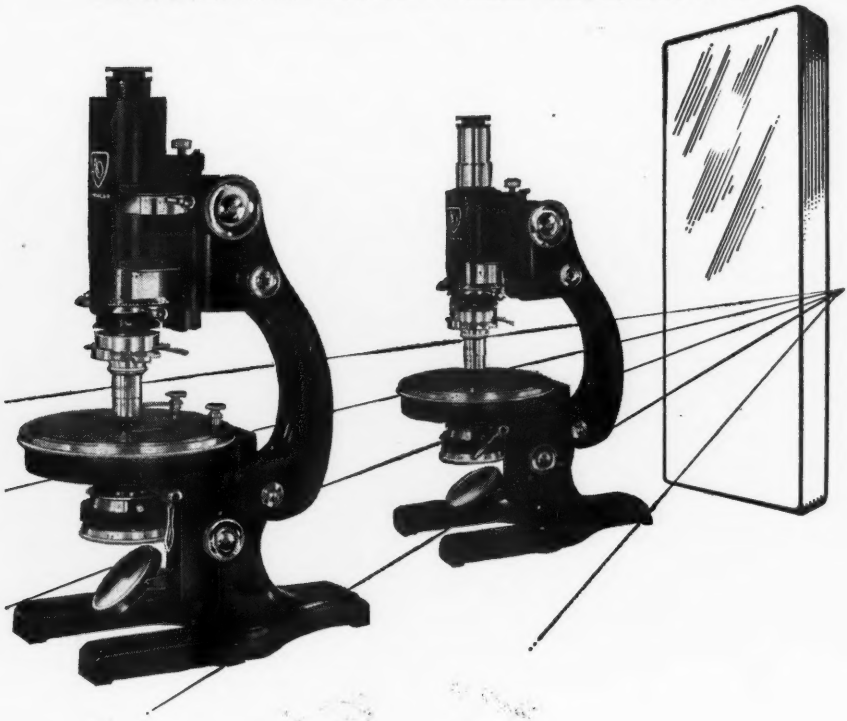

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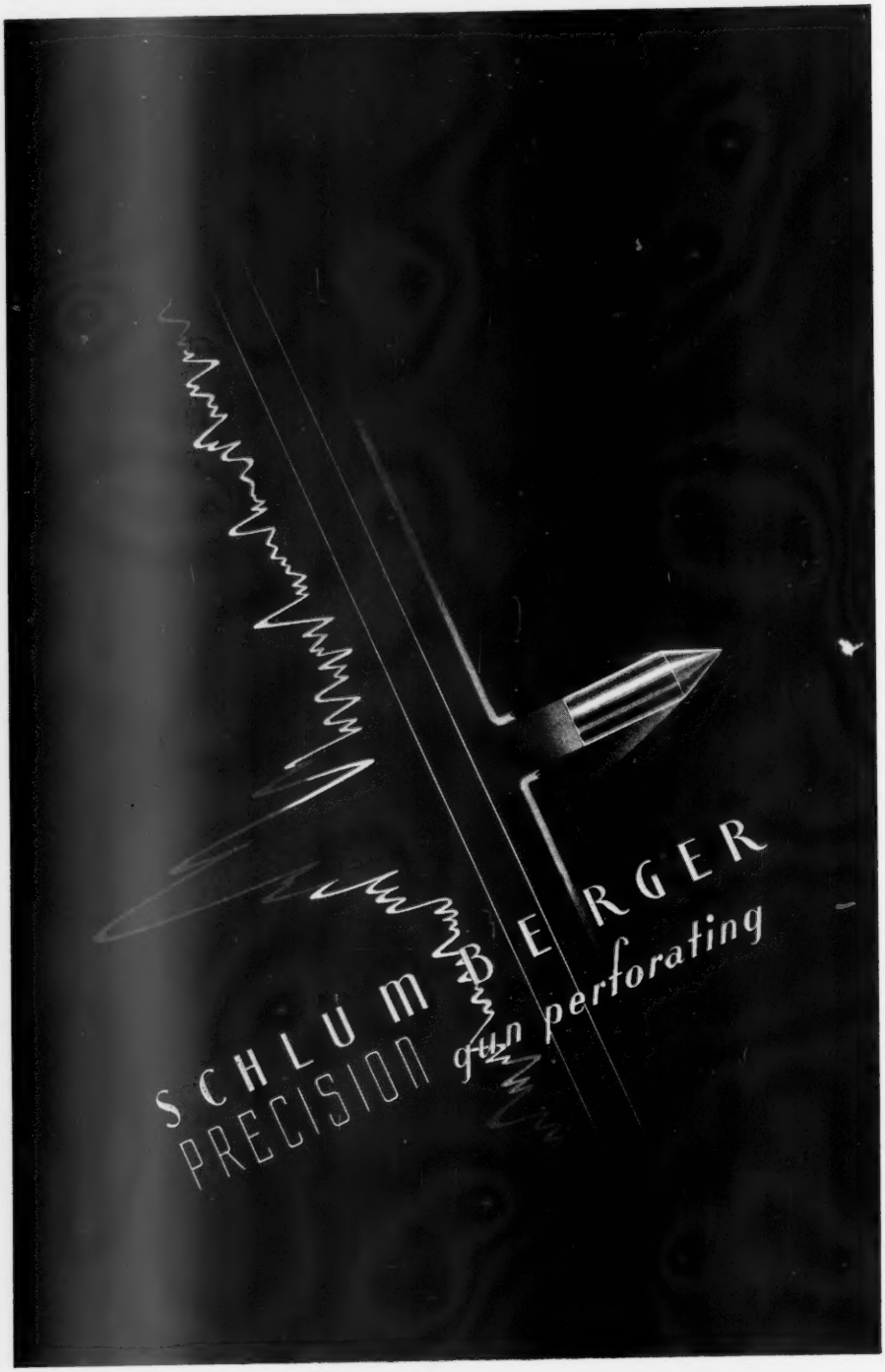
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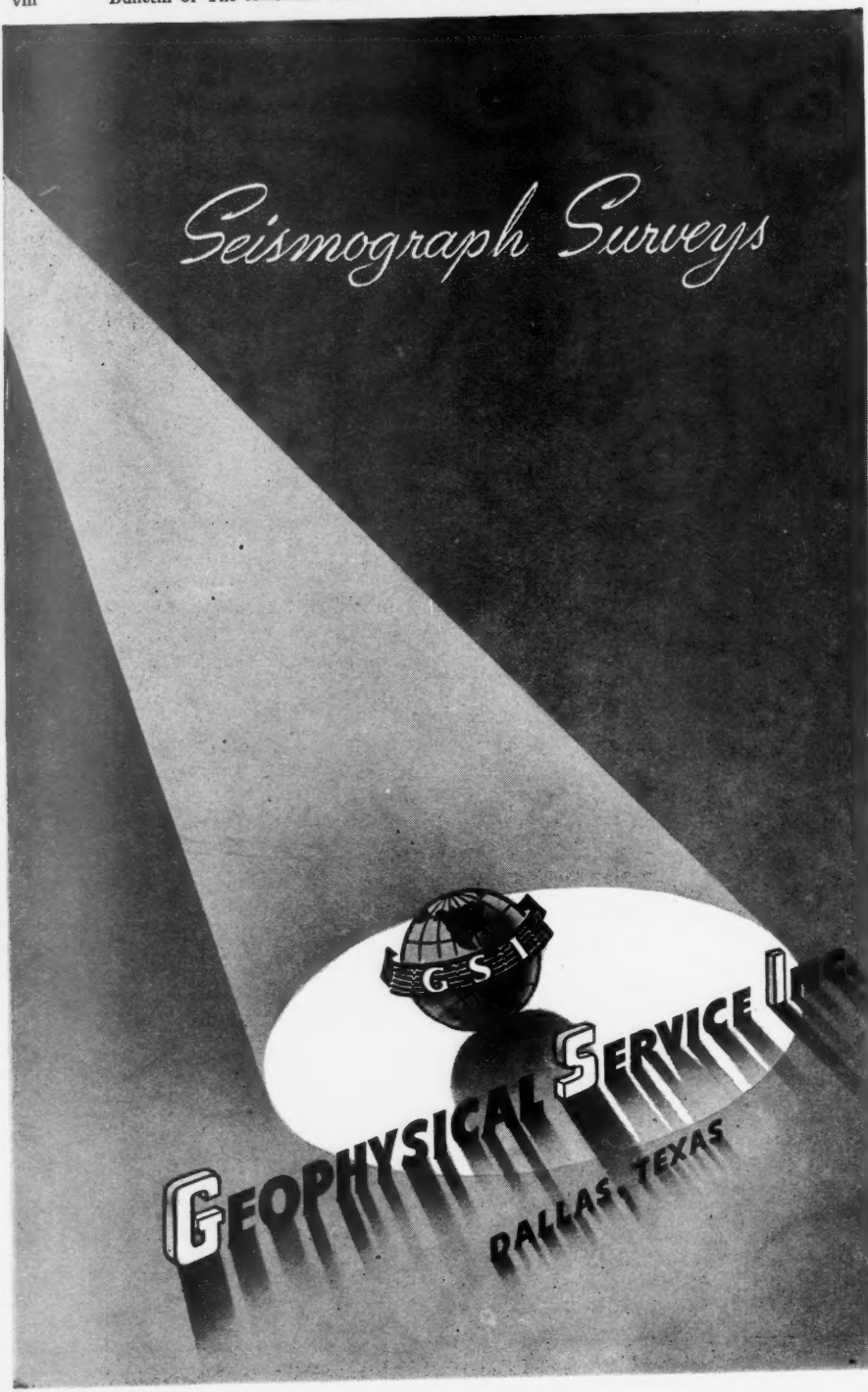
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Volume 29 Number 12

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

DECEMBER, 1945

QUATERNARY DEPOSITS OF TEXAS COASTAL PLAIN BETWEEN BRAZOS RIVER AND RIO GRANDE[1]

A. W. WEEKS[2]
Philadelphia, Pennsylvania

ABSTRACT

The Quaternary section, from oldest to youngest is divided as follows: Willis, Gay Hill, Bastrop Park, Uvalde, Asylum, Capitol, Beaumont (Sixth Street), Live Oak Bar (approximately of Beaumont age), First Street, Riverview, and Sand Beach.

The section was divided with the assistance of a series of profiles constructed across the Coastal Plain, with initial work along Colorado River from Austin to the Gulf. The best marker horizon was found to be the top of the Uvalde. Uvalde and younger deposits contain limestone pebbles; in surface exposures older Pleistocene deposits are leached of all limestone content. Along Colorado River the two terrace deposits next younger than Uvalde, Asylum and Capitol, contain much granitic material. Southwestward there is change in facies and Asylum and Capitol deposits are largely clay and silt. Younger deposits—Beaumont (Sixth Street), First Street, Riverview, and Sand Beach— are silt-covered in the vicinity of Austin and beneath each silt cover limestone gravel commonly is present.

Source of gravel in the present streams is largely the older gravel deposits over or through which streams now are flowing. Gravel sizes in the stream beds decrease coastward as limestone is dissolved; and, besides material in solution, clay, silt, and fine sand are carried to the Gulf.

The Recent delta of Colorado River, which first appeared above water about 1910 and by 1936, had extended a distance of approximately 5 miles to connect the mainland with Matagorda offshore bar, suggests a similar relationship between Live Oak bar and deposits of Beaumont and younger age farther inland.

Late in the Pleistocene a blanket of caliche (Reynosa) formed west of the approximate 32-inch rainfall line or in the zone of pedocal (carbonate-accumulating) soils.

[1] This paper and the two accompanying papers summarize part of a doctoral dissertation entitled "Late Cenozoic Deposits of the Texas Coastal Plain between Brazos River and Rio Grande" (Weeks, 1941), a summary of which was presented before the Association at the Houston meeting, April 2, 1941.

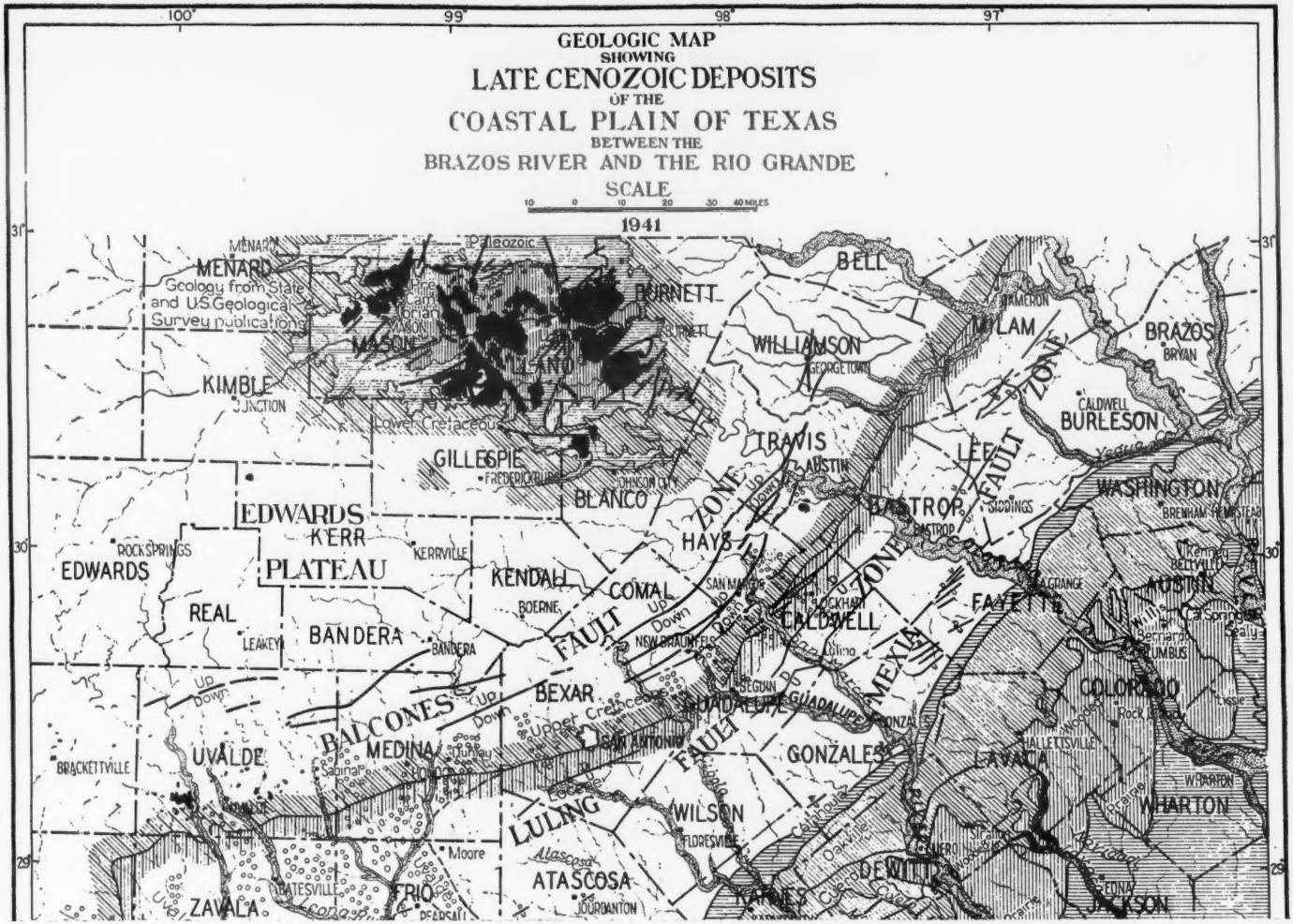
Illustrations in all three papers by the writer are numbered consecutively from Figure 1 of first paper to last figure in third paper to permit use of illustrations, particularly the geologic map, Figure 1, in each paper without necessity for duplication.

Manuscript received, June 4, 1945.

[2] Sun Oil Company.

For many courtesies and for helpful criticism and discussion of certain aspects of this paper, the writer is grateful to members of his supervising committee at The University of Texas in early 1941; to Adolph Knopf and C. O. Dunbar during later studies at Yale University; and to Jack B. Graham and Horace G. Richards during preparation of this summary. For editorial criticism, thanks are due Sidney A. Judson and W. Armstrong Price.

This paper and the two accompanying papers are dedicated to the memory of Captain Robert Hamilton Cuyler, who was killed on March 13, 1944, while on duty with the Army Air Forces. Before entering military service he was chairman of the aforementioned supervising committee.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OF THE
COASTAL PLAIN OF TEXAS
BETWEEN THE
BRAZOS RIVER AND THE RIO GRANDE
SCALE
10 0 10 20 30 40 MILES
1941
Geology from State and U.S.Geological Survey publications
Paleozoic
Lower Cretaceous
Upper Cretaceous
MENARD
KIMBLE
MASON
BURNET
LLANO
GILLESPIE
BLANCO
EDWARDS
KERR
PLATEAU
REAL
BANDERA
KENDALL
COMAL
BEXAR
MEDINA
UVALDE
ZAVALA
FRIO
ATASCOSA
LULING
WILSON
GONZALES
BELL
WILLIAMSON
TRAVIS
HAYS
CALDWELL
BASTROP
LEE
FAYETTE
MILAM
BRAZOS
BURLESON
WASHINGTON
AUSTIN
COLORADO
LAVACA
WHARTON
DEWITT
JACKSON
MEXIA FAULT ZONE
BALCONES FAULT ZONE
GUADALUPE FAULT ZONE
Up
Down

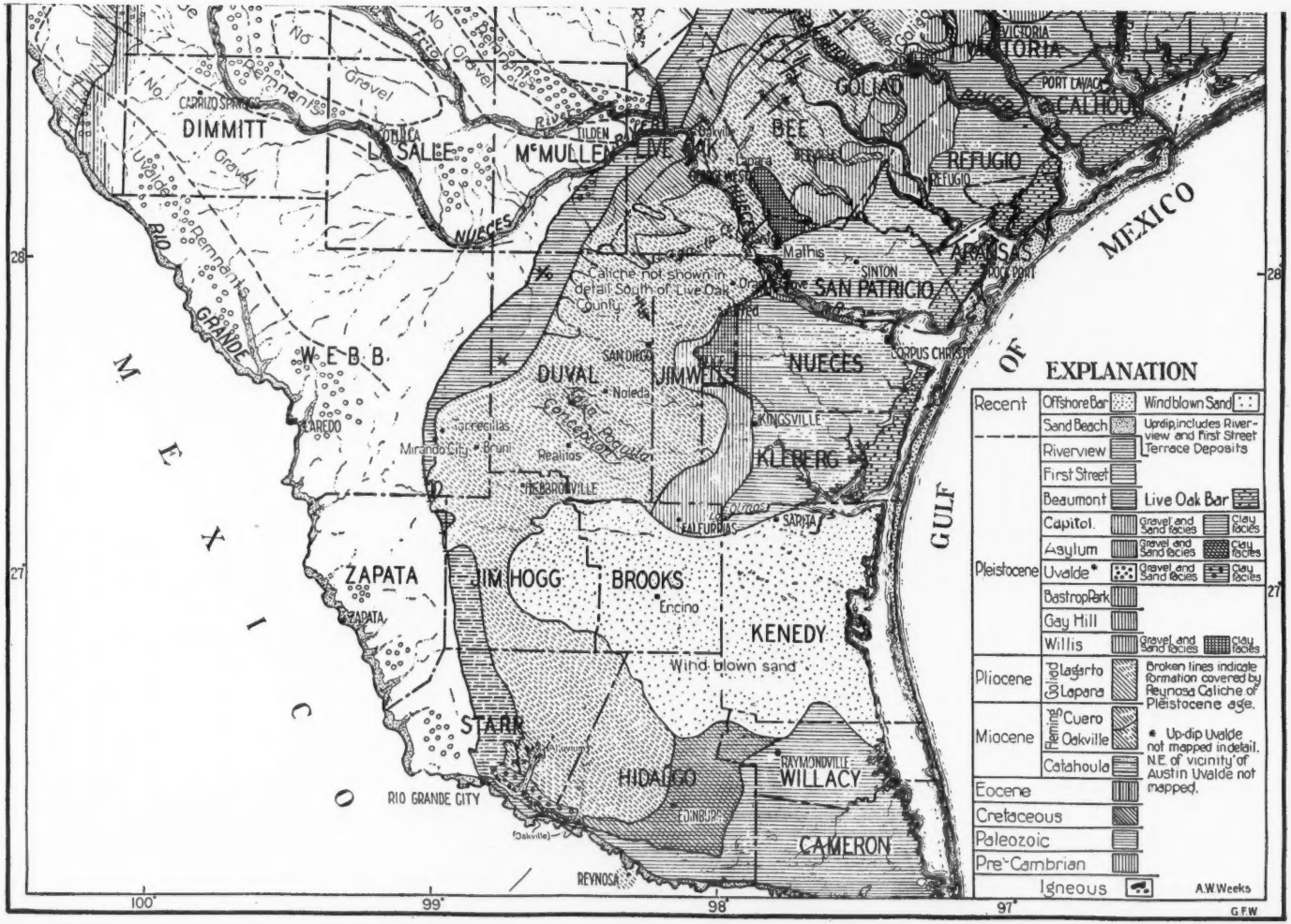


FIG. 1.—Geologic map showing late Cenozoic deposits of Coastal Plain of Texas between Brazos River and Rio Grande.

On the basis of stratigraphic position and leaching the Willis period of entrenchment and alluviation may be correlated with Nebraskan glacial and Aftonian interglacial ages, the Gay Hill, with the Kansan glacial and Yarmouth interglacial; the Bastrop Park, with the Illinoian glacial and Sangamon interglacial; and the Uvalde, with the Iowan and Peorian. The end of Beaumont time marks high sea-level, probably registering maximum retreat of Wisconsin ice.

The geologic picture of sedimentation during Quaternary time shows a series of coalescing deltas, each characterized by distinctive source material. The whole picture is complicated by coastward tilting, climatic changes, and a fluctuating sea-level.

INTRODUCTION

In this paper Quaternary deposits of the Texas Coastal Plain between Brazos River and Rio Grande are subdivided and described, their correlation with the glacial scale is suggested, and their geologic history is outlined.

The mapping of terrace deposits, especially where they can not be followed continuously, as along Colorado River, presents many difficulties and chances for error. In considering the over-all problem the writer has been guided by the fact that a certain number of stream terrace deposits have been identified at various places (type localities) along Colorado River, that the stream which deposited the material of these terraces flowed coastward and therefore the terrace deposits must slope coastward, that those terrace deposits older than Uvalde (best marker) probably slope coastward more steeply than the Uvalde and those younger that Uvalde probably slope coastward less steeply, and that deposits equivalent in age to the stream terrace deposits along Colorado River are present in the Quaternary section along the coast.

Time did not permit mapping all of the Quaternary deposits so that each could be displayed separately on the geologic map (Fig. 1). Along the coast the sand facies of the Willis, Gay Hill, Bastrop Park, Asylum, and Capitol are grouped under one symbol, and under another are grouped the clay facies of the Capitol, Beaumont, and younger deposits. Inland the details of the various gravel deposits, Gay Hill, Bastrop Park, *et cetera*, remain to be mapped. Areas mantled by Uvalde deposits are indicated. In general, the Uvalde and older terrace deposits are not obviously associated with the present streams, especially in their upper reaches, while the relation of the younger terrace deposits to the Recent streams is fairly evident.

All new names were reserved with Alice S. Allen, and later checked with M. Frances Willoughby, both of the United States Geological Survey, and were found to be available for use.

HORIZONTAL AND VERTICAL CONTROL

Horizontal control was obtained by the use of county road maps (scale 1 inch equals 2 miles), prepared by the Planning Survey of the Texas Highway Department; county ownership maps; and United States Army, United States Geological Survey, United States Bureau of Reclamation, and State Reclamation Department topographic sheets.

The stratigraphic units of the Quaternary were mapped and defined with the aid of several profiles across the Coastal Plain, so drawn that elevations could

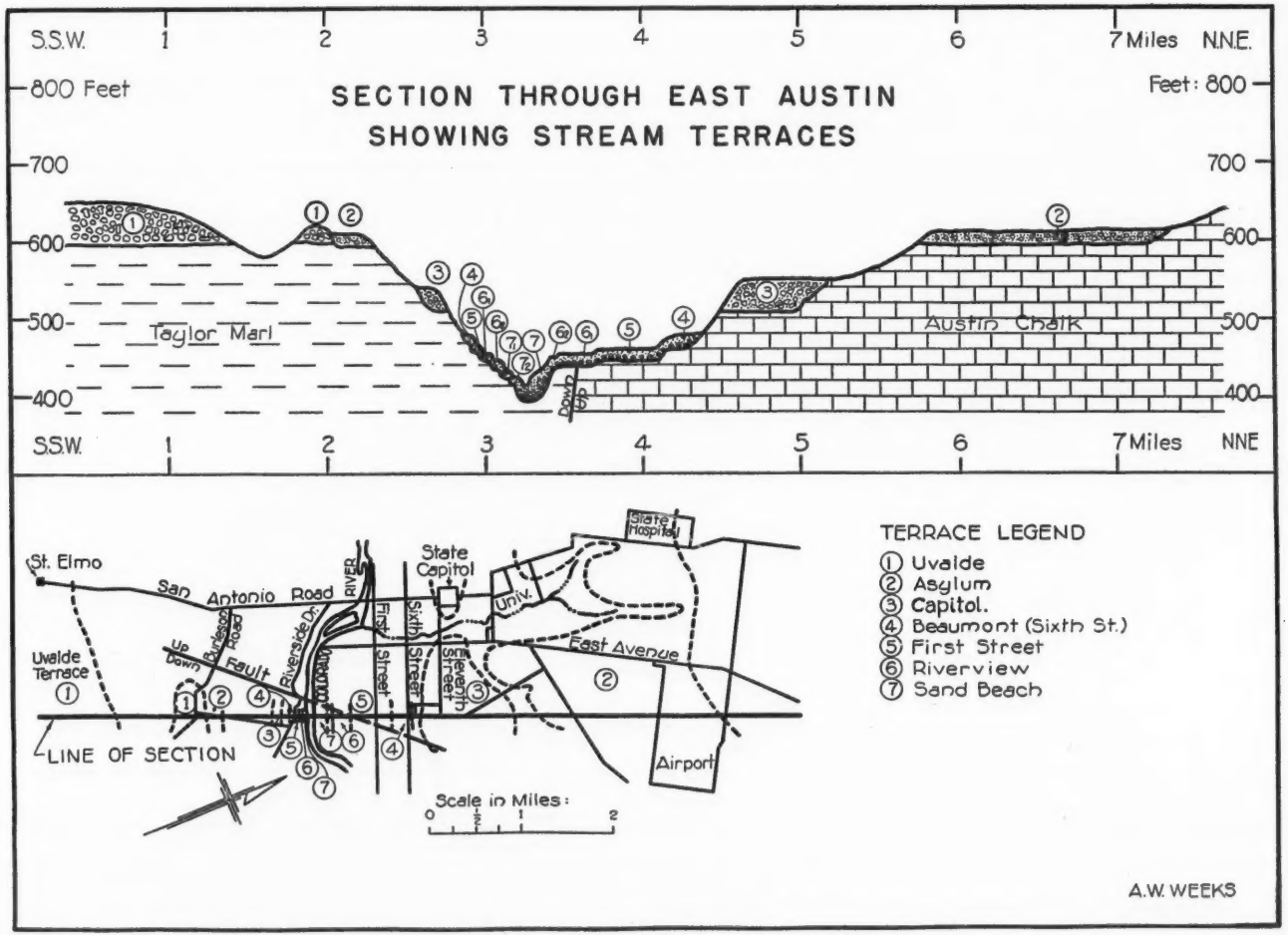
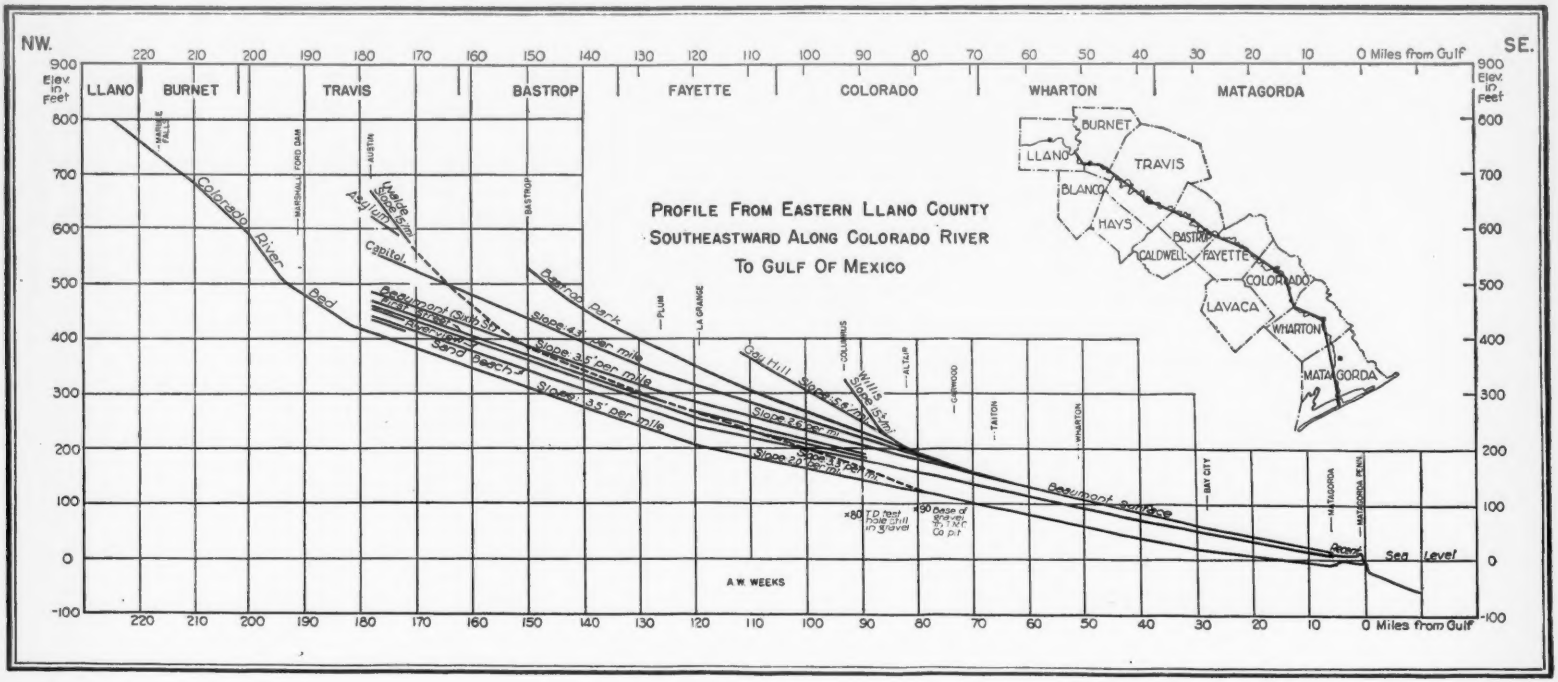


FIG. 2.—Section through east Austin showing stream terraces.


NW.
SE.
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 Miles from Gulf
900 Elev. in Feet
800 700 600 500 400 300 200 100 0 -100
LLANO
BURNET
TRAVIS
BASTROP
FAYETTE
COLORADO
WHARTON
MATAGORDA
Marble Falls
Colorado River
Bed
Marble Falls Strath
Austin Strath
Capitol
Beaumont (Sixth St.)
Beaumont (Austin)
Beaumont (Bastrop)
Beaumont (Altair)
Sand Beach
Bastrop Park
Gay Hill
Willis
Beaumont Terrace
Slope 4.5' per mile
Slope 3.5' per mile
Slope 3.5' per mile
Slope 2.6' per mi.
Slope 3.0' per mi.
Slope 3.9 ft./mi.
Slope 4.5 ft./mi.
Slope 4.5 ft./mi.
Slope 1.5 ft./mi.
Slope 1.5 ft./mi.
Slope 1

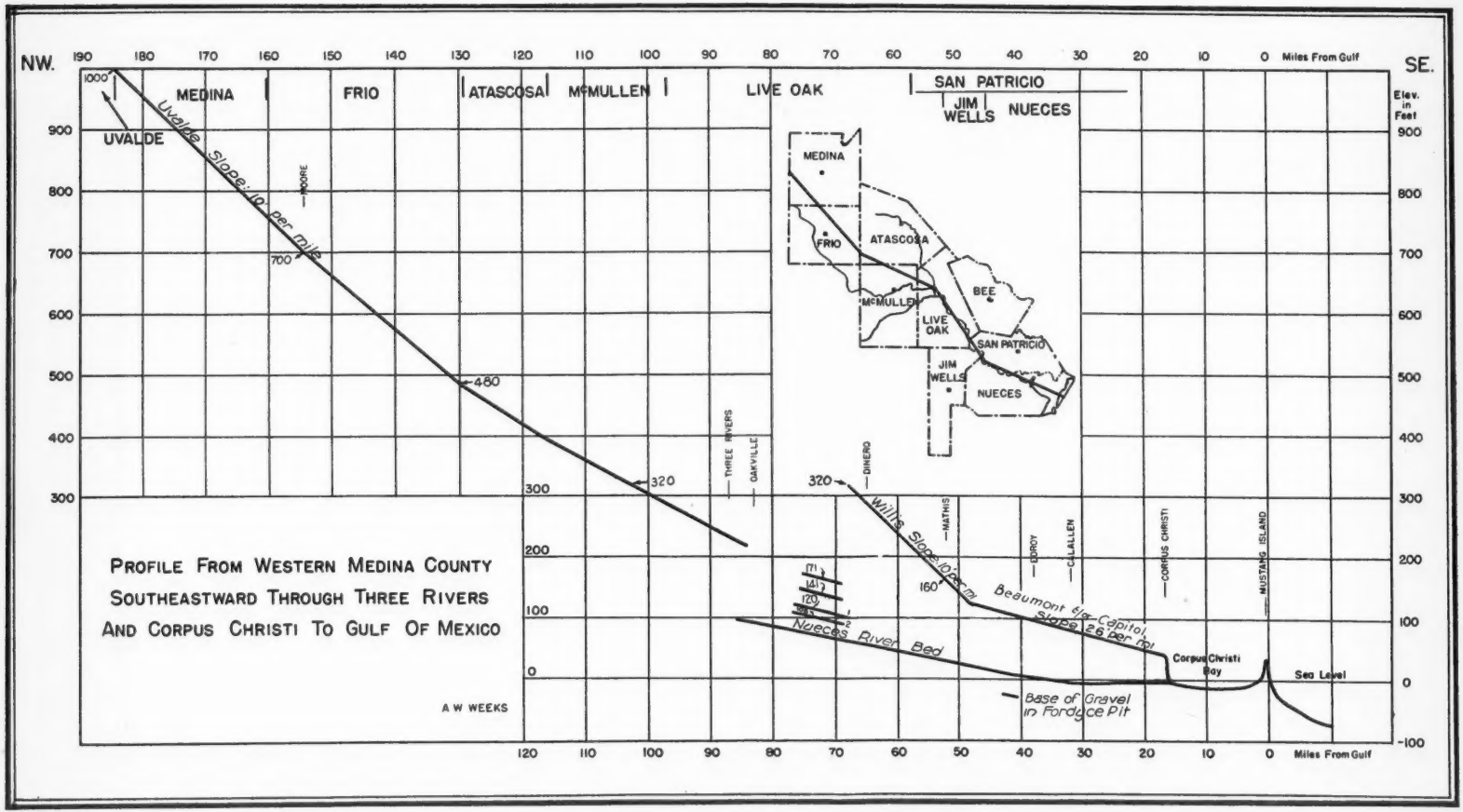


FIG. 4.—Profile from west-central Medina County southeastward to Gulf of Mexico. Willis and Beaumont (or Capitol) slopes indicated by line drawn along surface of ground. Line representing slope of Uvalde connects discontinuous erosion remnants.

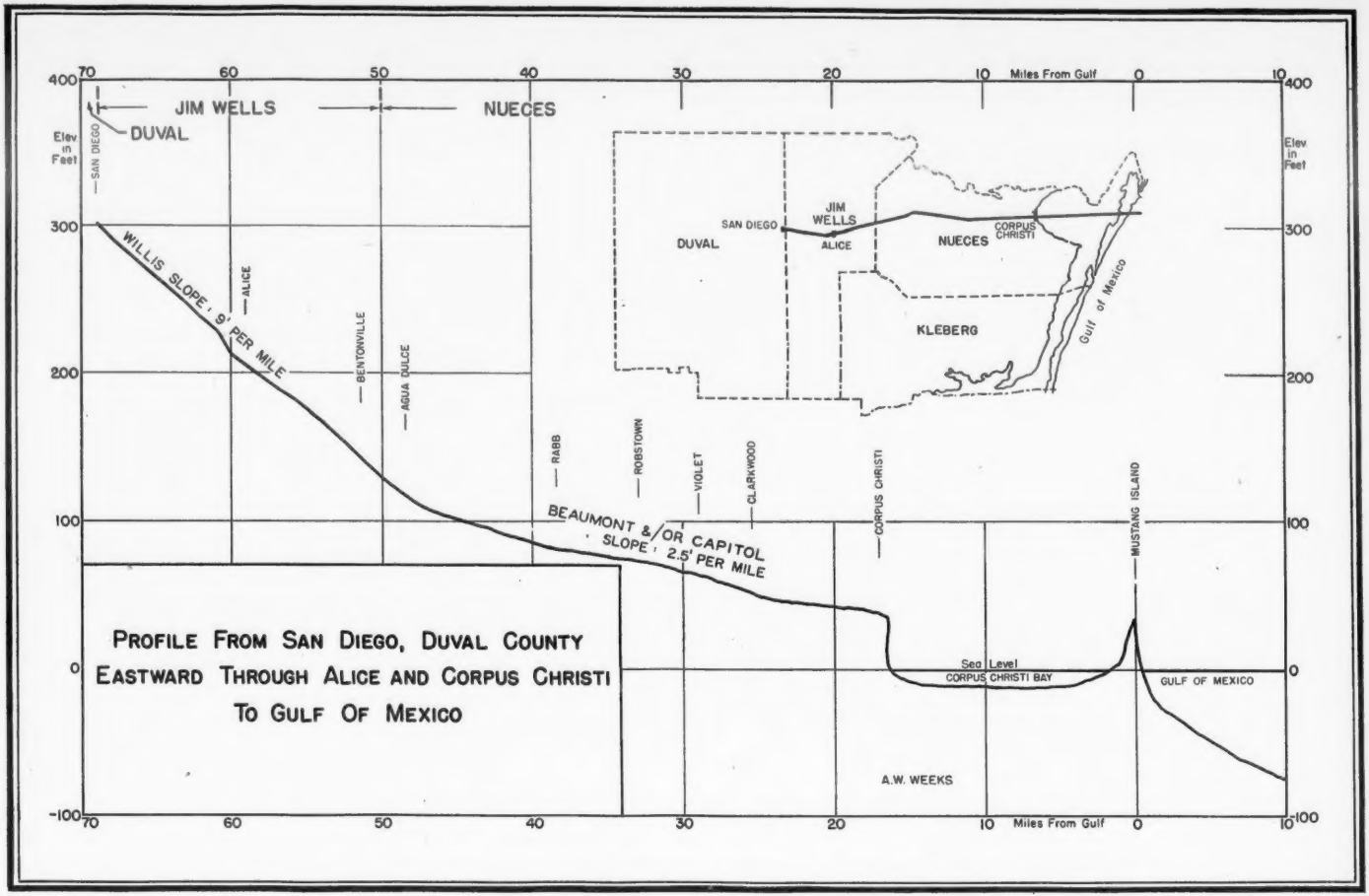


FIG. 5.—Profile from San Diego, Duval County, eastward through Alice and Corpus Christi to Gulf of Mexico.

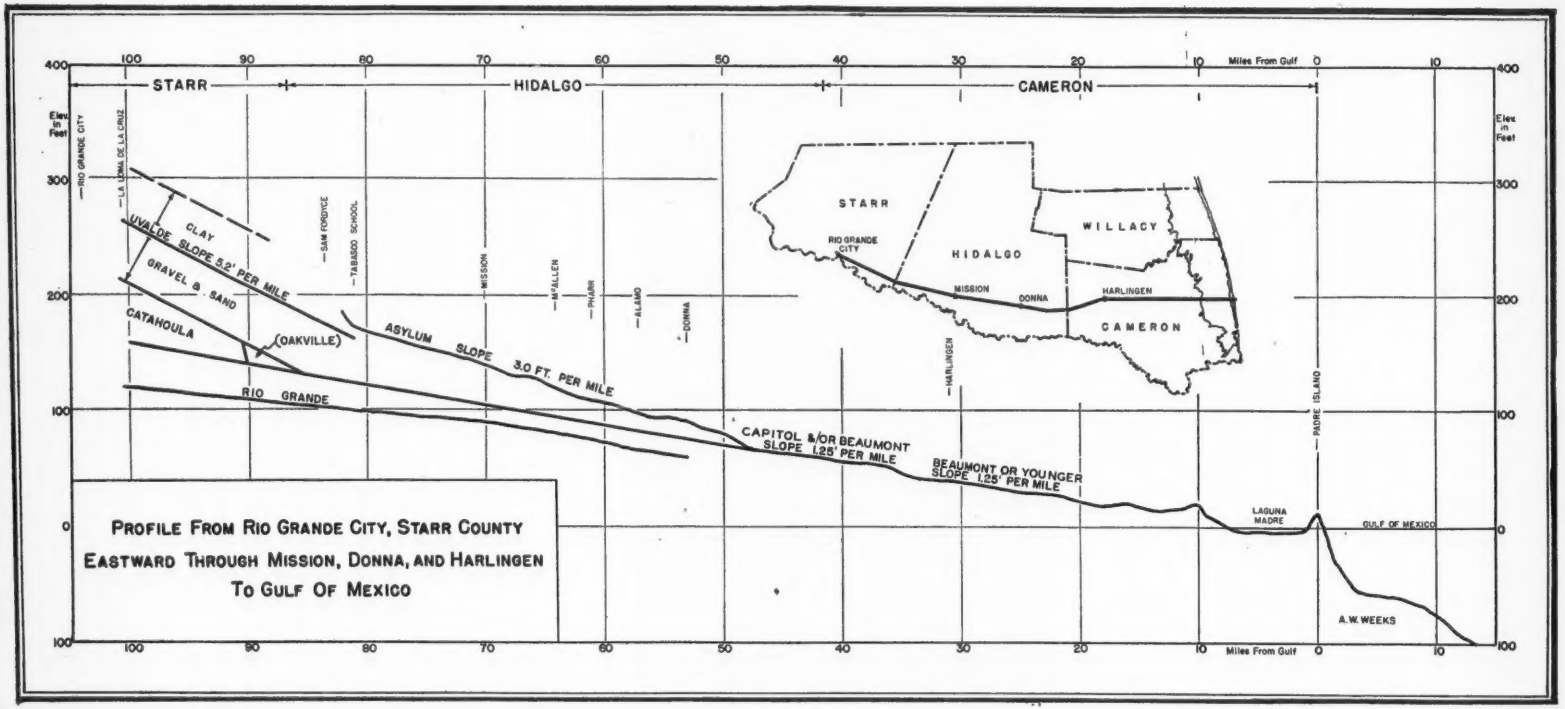


FIG. 6.—Profile from Rio Grande City, Starr County, eastward through Mission, Donna, and Harlingen to Gulf of Mexico.

be plotted to a 1-foot interval (Figs. 2, 3, 4, 5, and 6). A large number of the elevations used were obtained from the road profiles and bridge plans of the Texas Highway Department which contained elevations to 0.1 foot or less. Elevations in Austin were supplied by the City engineer. Some elevations were determined with altimeter and hand-level, and others, believed reliable, were obtained from State and United States Government topographic sheets, some of which were prepared on a 1-foot contour interval.

QUATERNARY DEPOSITS

Willis.—In the vicinity of Brazos, Colorado, and Guadalupe rivers, the Willis is composed of intermixed siliceous gravel and sand with sufficient clay

FIG. 7.—Willis sand and gravel with some clay binder. Railroad cut north of Sealy, Austin County. Note scattered siliceous pebbles in fine matrix.

to form a binder (Figs. 7 and 8). In the upper part of the formation there is considerable ferruginous material. The thickness ranges from a few feet to perhaps a maximum of 75 feet at the outcrop in Colorado and Austin counties. It thins to the southwest, and near Papalote in southern Bee County and in the Alice area of Jim Wells County, a Willis section of clay and silt overlies a thin Willis sand. In the Rio Grande region, Willis deposits have not been indentified.

The Willis overlies unconformably sandstone and clay beds of Pliocene and upper Miocene age. (Miocene dips coastward about 50 feet, and Pliocene about 25 feet per mile.) The age of the Willis has not been determined from fossil evidence. The writer considers the Willis to be Pleistocene since it fits well into the sequence of Pleistocene deposits, some of which (Uvalde and younger) have yielded identifiable vertebrate fossils, and since it has more the character of the overlying sand and gravel deposits than it has of the underlying Goliad for-

mation of Pliocene age. The coastward dip is difficult to obtain, but appears to range from 9 feet per mile in Jim Wells County to about 15 feet per mile in Austin County. The formation was named by John Doering (1935, p. 655).

Gay Hill.—In Fayette County, north of Colorado River, 6 miles northeast of the Colorado County line, and along the LaGrange-Columbus highway, there is a terrace deposit of siliceous gravel with elevation of 372 feet. The gravel extends down the hill for about 60 feet but part of this apparent thickness probably is

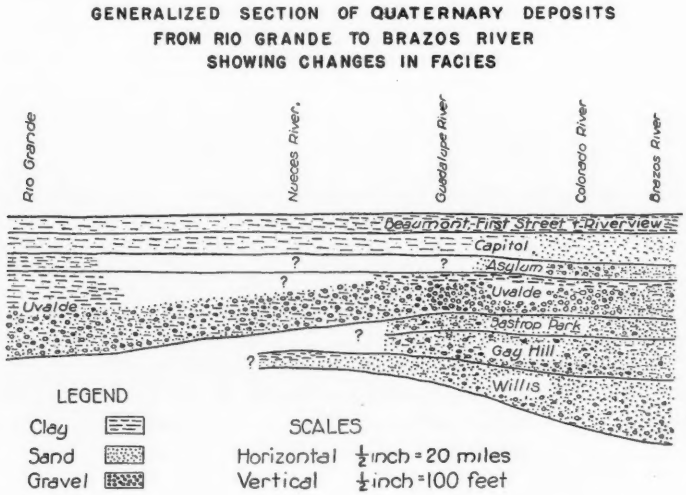


FIG. 8.—Generalized section showing changes in facies in Quaternary deposits of coastal area.

slump. For this terrace and terrace deposit, the name Gay Hill (from near-by Gay Hill cemetery) is proposed. Points along the terrace indicate a coastward slope near Gay Hill of 5.6 feet per mile.

Unfortunately, it is not possible, at this time, to show on the geologic map (Fig. 1) all of the scattered terrace deposits in addition to the Uvalde. Particularly in the northeastern part of the Coastal Plain under discussion, gravels of Gay Hill and Bastrop Park age mantle large areas of the Tertiary and Cretaceous formations.

Bastrop Park.—At Bastrop State Park, about 1½ miles east of Bastrop, there is a terrace deposit of siliceous gravel, with elevation of 525 feet, upon which part of the park and National Youth Administration camp are located. At one point

about 20 feet of gravel was measured. For this terrace and terrace deposit the name Bastrop Park is proposed. Coastward other points on the terrace were mapped. The unconsolidated nature of the Gay Hill and Bastrop Park deposits differentiates them from the Willis, which has some clay binder, and the lack of calcareous material in the Willis, Gay Hill, and Bastrop Park differentiates them from the Uvalde.

Uvalde.—The name Uvalde was applied by R. T. Hill (1891, pp. 367–68) to the remnants of a formation exposed on terraces north of the Rio Grande region. Hill and T. W. Vaughan (1898, p. 247) applied the name Uvalde to the highest terrace deposit in and adjacent to the Edwards Plateau. The writer is restricting the name Uvalde to the deposits here described, even though it is possible the Uvalde of other geologists perhaps included the writer's Uvalde as well as remnants of older terrace deposits which are no longer in place and which have come down from higher levels as erosion progressed. In general however, west of San Antonio, gravels older than Uvalde thin and disappear, and the Uvalde gravels occupy the high gravel-covered areas as indicated on the general geologic map (Fig. 1).

The oldest and highest terrace and terrace deposit shown on the section at Austin (Fig. 2) is the Uvalde, which is well exposed south of Colorado River at the settlement of St. Elmo, where it has an elevation of 663 feet. The terrace is identified by its elevation, by its slope, and by the material composing the deposit. The surface of the terrace shows chert pebbles and cobbles in a matrix of dark-colored soil, but gravel pits in the terrace deposit show an abundance of well rounded limestone pebbles below a leached upper zone. Pebbles of quartz and quartzite are common, but most of the gravel is limestone and chert with some reworked Cretaceous fossils.

The region around Austin and westward is in the zone of pedocal (carbonate-accumulating) soils. In the normal process of soil development calcareous material, leached from the upper part of the soil, was carried to the general level to which rain water penetrates and was there precipitated to form caliche (Weeks, 1933, pp. 472–75). Younger deposits are not leached as much and do not contain as much caliche as do older. Deposits along Colorado River east of Austin are in the zone of pedalfer (non-carbonate-accumulating) soils. There, in Quaternary deposits older than Uvalde, no calcareous material was noted.

Granitic material was not found in the terrace deposit at St. Elmo, but 6 miles northeast of Austin on the Manor road well weathered granite pebbles and boulders were noted scattered through the Uvalde gravel in pits from which highway material is obtained.

Thickness of the Uvalde terrace deposits, like all such deposits, probably varies. Core-drill work west of Lockhart, Caldwell County, indicates approximately 30 feet of gravel in the Uvalde formation at that point (Weeks, 1930, p. 917).

At Austin, the Uvalde dips southeastward about 15 feet per mile, but the dip gradually flattens coastward. A few miles east of Austin the Uvalde is crossed by younger terrace deposits, thus becoming lost at the surface; but the limestone pebbles, characteristic of the Uvalde, can be observed in cuts, pits, and the Colorado River bed.

In a recent paper, R. W. Mathis (1944, p. 87) states that the Uvalde near Austin does not occur at a definite level, does not form a continuous deposit, contains occasional limestone pebbles, and occurs on hill tops at elevations of 320 feet above the river level (river level is about 400 feet). The writer does not agree with these views. In the vicinity of Austin, gravels at elevations above the Uvalde (higher than 663 feet at St. Elmo) are the remains of older Pleistocene deposits, and those observed were not in place.

Mathis describes the Delaney gravel, located west of Austin and occupying a level between the Uvalde and Asylum deposits. Since abundant limestone material is present in Uvalde and younger deposits, Mathis' omission of limestone pebbles in discussion of the Delaney gravel suggests that either he failed to see them or that the Delaney gravel came down from higher levels as erosion progressed and therefore is not in place.

In the Rio Grande region, the Uvalde is composed of a gravel section with thickness of about 55 feet overlain by approximately 45 feet of silty clay (Figs. 6 and 21). In many parts of the updip Coastal Plain, there is sufficient clay to form good farm land, so it is entirely possible Uvalde clay and silt once extended farther northeastward than the Rio Grande region (Fig. 8).

The absence of recognizable Pleistocene sediments older than Uvalde along the Rio Grande, at least on the Texas side, raises the question of the age of the Rio Grande in the Valley region. If it were in existence during Willis, Gay Hill and Bastrop Park time, then the large amount of erosion and deposition during Uvalde time has erased the evidence, thereby suggesting that any earlier Pleistocene stream must have been much smaller than its Uvalde descendant.

In the Uvalde gravel at La Loma de la Cruz, Starr County, Texas, the lower jaws and teeth of *Equus* cf. *fraternus* Leidy of Pleistocene age were obtained (Bailey, 1926, p. 59).

Streams of Uvalde time cut deeply into the Coastal Plain and carried their load sufficiently far gulfward to be covered later by younger deposits, so that to-day no Uvalde formation is exposed in a belt across the coastal area as are the Willis and Beaumont. At Columbus, Colorado County, gravels are found 108 feet below the First Street terrace of Colorado River; near Eagle Lake, Colorado County, 90 feet below the First Street terrace (limestone material was not found to the mined depth of 45 feet, indicating this deposit may be, but is not necessarily, older than Uvalde); near the Brazos River east of Wallis, Austin County, 113 feet below a Recent terrace; north of Victoria, Victoria County, 80 feet below the Beaumont surface (here no limestone pebbles were noted to the mined depth

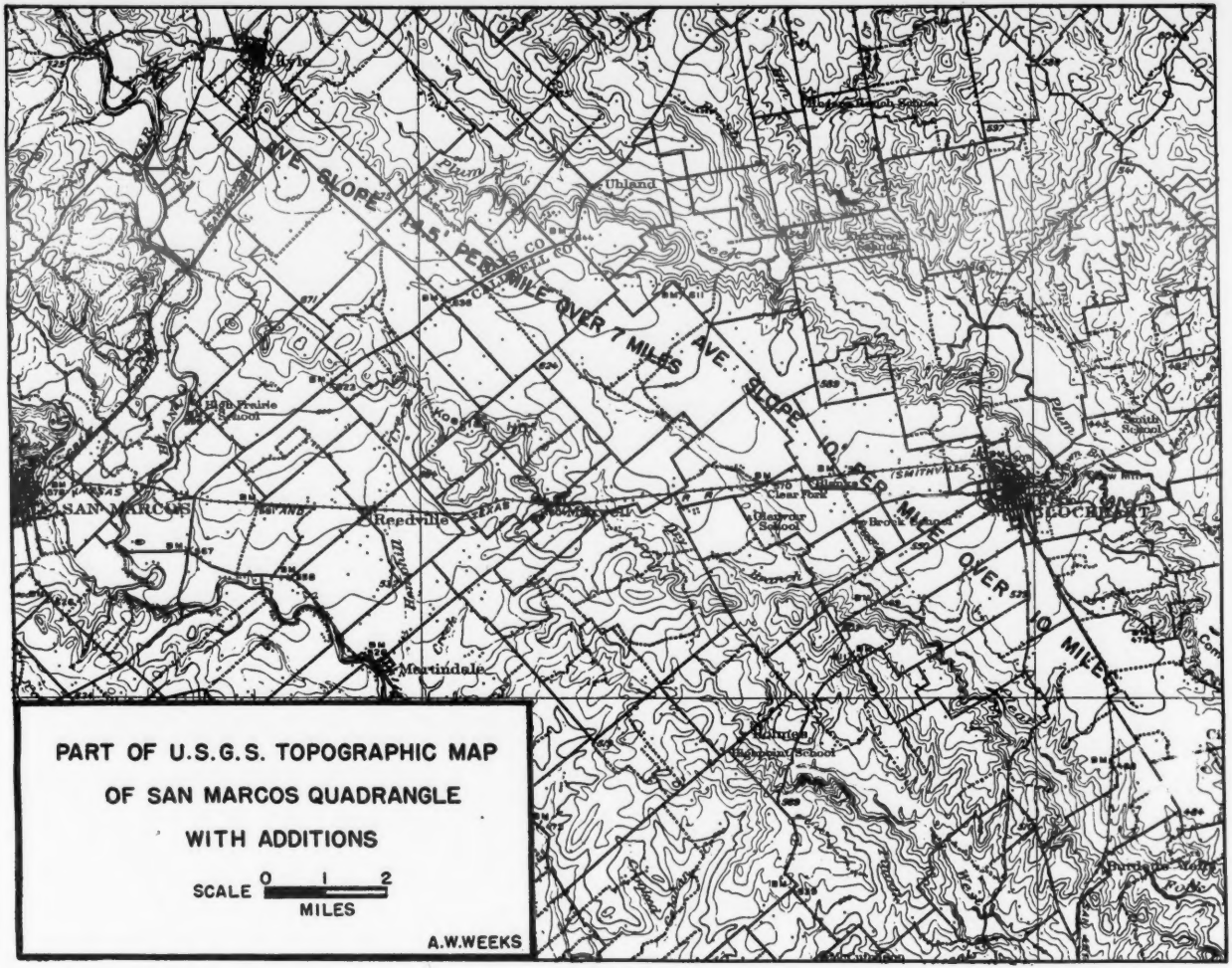


FIG. 9.—Uvalde terrace. Part of San Marcos Quadrangle topographic sheet showing position and slope of Uvalde terrace from Kyle in Hays County southeastward through Lockhart in Caldwell County. Ridge southwest of Uvalde terrace, on which Koeglar Hill is located, is covered with siliceous gravel older than Uvalde.

of 30–35 feet); and at the Nueces River near Calallen, Nueces County, 28 feet below the Sand Beach terrace. These are of considerable economic importance as evidenced by many gravel-mining operations.

An example of a Uvalde terrace is shown on the San Marcos Quadrangle topographic sheet from Kyle in Hays County, southeastward through Lockhart in Caldwell County (Fig. 9). Southward, where Uvalde deposits are lost at the surface, the Uvalde stream occupied the same course as the present San Marcos River.

From northwestern Medina County a Uvalde terrace deposit (Fig. 4) was traced as far as Live Oak County where it is obscured by younger terrace deposits more closely associated with the present Nueces River. This deposit, which contains limestone pebbles beneath a leached upper surface of siliceous gravel, slopes 10 feet per mile in the upper reaches of the Coastal Plain and gradually flattens southeastward. The old Uvalde River, a name which we may properly call the stream which laid down the terrace deposit, obviously is not associated with the present drainage, except in its lower reaches. Beside this Uvalde River channel there then rose divides which now, unprotected by a gravel mantle, lie at lower elevations with the Uvalde capping the present hills. The Uvalde now constitutes the highest terrace level of the updip portion of this region.

Asylum.—Along Colorado River, Asylum and the next younger deposit, Capitol, contain an abundance of granitic material indicating Colorado River was cutting into the pre-Cambrian granite of the Central Mineral Region during the period of their deposition. Limestone material, as in Uvalde and all younger deposits, is present also but it is overshadowed by material from the pre-Cambrian. At one locality near Austin, a thickness of 15 feet of Asylum deposit was measured (Fig. 2). The coastward slope is difficult to obtain, especially since in Austin there is indication that the Asylum consists of several closely spaced terrace levels.

The writer (1941, p. 248), after noting the heavy-mineral work then underway by F. M. Bullard (1942) and his students along the shore line of the Gulf of Mexico, suggested heavy-mineral studies in order to define more closely the terrace deposits containing granitic material. Mathis (1944, pp. 86–93) undertook such studies and according to his conclusions the Asylum terrace has a lesser coastward dip than that which the writer assigned to it near Austin in 1941 and therefore extends coastward at least as far as LaGrange, instead of being crossed between Austin and LaGrange by the Capitol terrace. For the purpose of differentiating between the terraces it is disappointing that the differences in heavy-mineral content of the Asylum and Capitol deposits are not more pronounced.

The Asylum was named by Hill and Vaughan (1898, pp. 244–50) from an occurrence at the Austin State Hospital, Austin, Texas. It was further described by Hill (1901, p. 352).

Capitol.—The name Capitol was given by Hill and Vaughan (1898, pp. 244–

50) and later by Hill (1901, p. 352) to a terrace deposit near the State Capitol at Austin. Material of this terrace is well exposed directly east of the State Capitol, and from there eastward to Chicon Street. Tillitson Institute, in the quadrangle south of 11th Street and west of Chicon Street, stands on material of this terrace. East of Austin about 40 feet of material was measured in the Capitol terrace deposit (Fig. 2).

Traced coastward along Colorado River, the surface of the Capitol terrace appears to coincide with the surface of a sand and sandy clay formation near Lissie, Wharton County, Texas, to which Alexander Deussen (1914, pp. 78–9) gave the name Lissie. On the basis of priority the name Capitol has preference over the name Lissie. In addition the terrace deposits at Austin are fairly well defined, whereas the Lissie as originally described is now known to be composed of several ages.

The skull of *Equus francisci* Hay was taken from a depth of 25 feet in a well at Lissie, Wharton County (Deussen, 1924, pp. 108–09). Since at Lissie, the deposit of one division of the Pleistocene may be entrenched on, or overlap, that of another, the name of the Pleistocene formation from which this fossil was obtained can not be stated.

During Capitol and Asylum time, the Brazos and Colorado rivers carried considerable clastic material; but the Guadalupe and Nueces rivers heading in the limestone section of the Edwards Plateau, and the Rio Grande cutting through a vast Cretaceous limestone section, carried largely calcium carbonate in solution, clay, and silt; hence, the change in facies from northwest to southeast (Fig. 8). On the geologic map (Fig. 1) the clay facies of the Capitol is not separated from the Beaumont.

Beaumont (*Sixth Street*).—In Austin, along Sixth Street east of Congress Avenue, there is a terrace deposit, approximately 70 feet below the surface of the Capitol terrace, composed of 5 to 10 feet of dark gray to reddish silt overlylng limestone gravel. The slope of the terrace averages 3.5 feet per mile near Austin, but becomes less coastward. Downstream along Colorado River the terrace appears to join the surface of the Beaumont, a name given by C. W. Hayes and William Kennedy (1903, pp. 27–8) to a dark-weathering clay and silt formation lying above the Lissie and typically exposed near Beaumont, Texas. For this terrace and deposit at Austin, the writer (1940, p. 1952; 1940, p. 15; 1941, p. 99) used the name Sixth Street. It appears desirable to retain the name for local use at Austin, especially since the relation of younger terrace deposits (First Street and Riverview) at Austin to formations near the coast has not been completely determined. (The references to previous use of the name Sixth Street also apply to the names: First Street, Riverview, and Sand Beach.)

In fresh exposures, colors of Beaumont clays range from bluish gray to green to yellow, tan, and red. Calcareous nodules are common and, in places, selenite is abundant. Although the formation is composed largely of clay and silt, sand lenses also are present.

Above water level at the east side of Carancahua Bay, Jackson County, and at the east side of Lavaca Bay, Calhoun County, a 2½-foot bed of oyster shells is present in clay, presumably of Beaumont age (Fig. 10). These shells were deposited during a time of higher sea-level than that of to-day. Data on Quaternary invertebrate fossils in Texas are given by Horace G. Richards (1939, pp. 1885–98).

South of San Antonio, near Bergs Mill and Mission San Juan de Capistrano, and along San Marcos River in Guadalupe and Caldwell counties, calcareous pisolitic gravel is present in terraces believed to be Beaumont in age. This

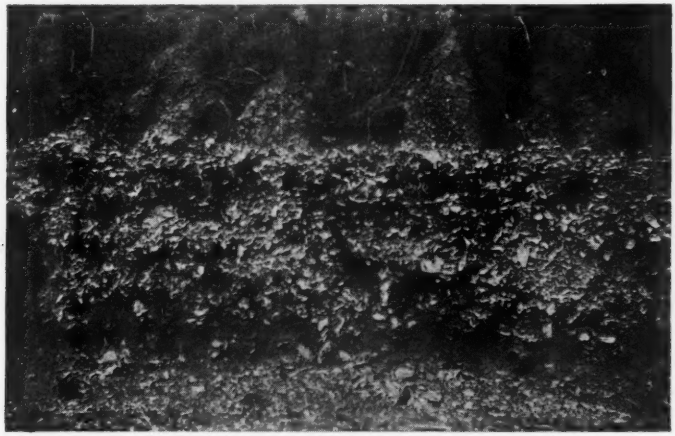


FIG. 10.—Oyster shell bed in clay formation probably Beaumont in age. South side of State Highway 35 at east side of Carancahua Bay, Jackson County.

calcareous gravel, each pebble of which is composed of concentric rings of calcium carbonate formed about a central nucleus, probably was formed in waters which rose from the Edwards limestone along faults. Chlorophyll-bearing algae (W. H. Bradley, 1929, pp. 203–23), which by their photosynthesis extract carbon dioxide held in solution in natural waters as bicarbonate and thus precipitate calcium carbonate, may have aided in the formation of the pisolites. These pisolites were carried to their present location and deposited without being cemented together.

E. H. Sellards (1940, pp. 1627–57) presents interesting data on terrace deposits and paleontological and archeological discoveries (Folsom, Yuma, and Clear Fork material) along Blanco Creek in Bee County. The writer has not studied the deposit in the field but Sellards considers it to be Beaumont in age. The problem of correctly dating the deposit beneath each terrace, especially where one deposit lies entrenched in that of another, is of upmost importance in synthesizing the results of paleontological and archeological discoveries.

First Street.—At the corner of First and Chicon streets, Austin, Texas, there is a terrace with elevation of 461 feet which lies 18 feet below the Beaumont (Sixth Street) terrace. It extends much of the length of First Street east of Congress Avenue, and is composed of dark-weathering silt overlying limestone gravel. For this terrace and its deposit the name First Street is proposed. The terrace forms a rich farm land along the streams and many towns are located on it. In Calhoun County, the deposit inland from Live Oak bar may be First Street in age. The surface of this deposit perhaps is the same as the Ingleside terrace of Price (1933, p. 919) and the Recent of Deussen (1924, geologic map).

Riverview.—At Austin this terrace lies about 8 feet below First Street; a bench about 6 feet lower is designated Riverview No. 2. Like First Street and Beaumont (Sixth Street) deposits, it is composed of dark-weathering silt overlying limestone gravel. For the terrace and terrace deposit the name Riverview is proposed from Riverview Street in Austin. Its type locality is at the junction of Riverview and Chicon streets.

Sand Beach.—This terrace lies about 20 feet below Riverview. A second bench designated Sand Beach No. 2 lies about 5 feet lower, or about 10 to 15 feet above low water level in Colorado River at Austin. For this terrace and terrace deposit the name Sand Beach is proposed from Sand Beach Reserve along the north side of Colorado River at Austin. The upper part of this terrace is largely sand and silt; it is the first area of overflow in time of flood. A test hole drilled in advance of the digging of the new fish hatchery well on the Sand Beach terrace at the north side of Colorado River near the end of Waller Street encountered silt and sand to a depth of about 8 feet and then penetrated largely limestone gravel and sand to a depth of 38.5 feet below which was Austin chalk.

Bed of Colorado River.—In the bed of Colorado River at Austin there is a section of gravel, largely limestone, but containing granitic and siliceous pebbles also, extending in places to a depth of 40 feet, or 50 to 60 feet below the Sand Beach terrace, according to data obtained from gravel companies (Fig. 11). The grade size of gravel in the river varies. Although smaller sizes predominate, boulders up to six inches in diameter are common. Colorado River entrenched its channel to the base of the gravel and then filled it with the material seen to-day. Alluviation of channel probably was caused by deposition at the mouth and decrease in volume of water.

A tooth identified as *Mastodon americanus* Kerr by E. H. Sellards and Joseph T. Gregory was brought up in a drag-line bucket in July, 1940, from a pit 25 to 30 feet deep in the bed of Colorado River, located 500 feet east of the Austin bridge on the San Antonio road.

Source of gravel in the present streams is largely the older gravel deposits over or through which streams now are flowing. Gravel sizes in the stream beds decrease coastward as limestone is dissolved. Besides material in solution, clay, silt, and fine sand are carried to the Gulf. Beyond the point between Columbus

and Garwood where the Uvalde limestone pebbles disappear beneath the Colorado River bed, no limestone material was noted except limestone concretions and calcareous clay which had fallen into the river from the Beaumont formation exposed along the banks.

Recent Colorado River delta.—About 1831 a raft of logs and other débris formed in Colorado River just above the town of Matagorda. The raft moved by accumulation upstream and rotting downstream. Removal of the débris from the stream by a dredging company, a job which required about 4 years to complete,

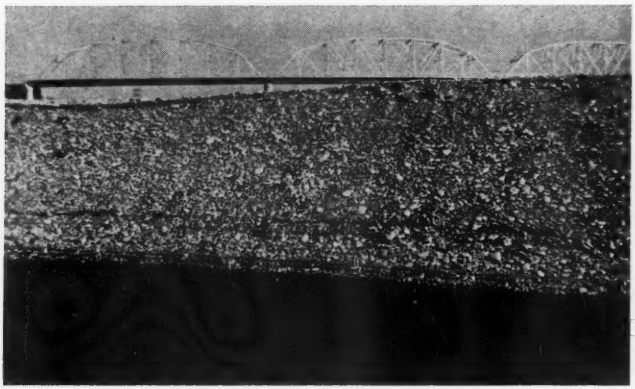


FIG. 11.—Gravel in Colorado River at Austin, Travis County. Much of the material of this deposit is limestone. Upper silt cover, approximately 10 feet thick and extending to level of Sand Beach terrace, has been eroded. Coastward, material in river bed becomes finer, and at the Gulf largely clay and silt are deposited.

began in early 1926. Removal of the raft permitted silt in the river to be carried gulfward, and thus began the remarkably rapid building of the delta.

Growth of the Colorado River delta by October, 1930, and April, 1941, is shown in Figures 12 and 13. In 1936 a channel was cut through the delta and Matagorda Peninsula to the Gulf of Mexico. An automobile road has been constructed from Matagorda to the Gulf and large trees and other vegetation now mark the site of waters formerly constituting a part of Matagorda Bay. In August, 1940, an inter-coastal canal was cut across the delta and Colorado River not far from Matagorda City. Pictures taken a few months later show the canal filled with clay and silt carried by the river. Growth of the delta severely limited the once flourishing oyster-fishing industry in Matagorda Bay.

In the Recent material of the delta were noted 7 species of pelecypods; 2 species of small gastropods; several species of foraminifera, such as *Rotalia, Elphidium, Quinqueloculina, Globigerina;* and three species of ostracods. The

FIG. 12.—Colorado River delta, October, 1930. (Courtesy Edgar Tobin Aerial Surveys.)

FIG. 13.—Colorado River delta and vicinity, April 1, 1941. Shows intercoastal canal along mainland and road along dredged Colorado River channel from town of Matagorda across delta and Matagorda Peninsula to Gulf of Mexico. (Photograph courtesy United States Army Engineer Office, Galveston, Texas.)

following pelecypods and gastropods were sent to the United States National Museum and were identified by Paul Bartsch (letter, March 24, 1941).

Tagelus gibbus Spengler
Polymesoda caroliniana Bosc.
Chione cancellata Linné
Rangia cuneata Gray
Phacoides pectinatus Gmelin
Mulinia Lateralis Say (young)
Leda acuta Conrad (young)
Acteocina candei d'Orbigny
Cingula sp. (young)

A survey of the delta which the Colorado River is now building in the Gulf of Mexico was made in August, 1940, by the United States Engineer Office. At the mouth of the river the water is about 10 feet deep, shallows 1,000 feet out to 1 foot, and then reaches a 10-foot depth about 2,000 feet from shore.

One can not view the growth of the Colorado River delta from the mainland to Matagorda Peninsula during Recent time without considering that Live Oak bar, lying inland from the present offshore bar and extending southwestward from Port O'Connor through Goose Island, Rockport, Aransas Pass, and Flour Bluff toward Baffins Bay (Fig. 1), has much the same relation to Beaumont and younger deposits as the Recent delta in Matagorda Bay has to Matagorda offshore bar.

Live Oak Bar.—Inland from the recent offshore bar there is a line of sand ridges extending through portions of Kleberg, Nueces, San Patricio, Aransas, Refugio, and Calhoun counties (Fig. 1). They were mapped by Deussen (1924) and were referred to as "Live Oak mature offshore bar" by Price (1933, p. 918).[3] The position of sediments of Beaumont and younger age lying inland from this feature suggests that originally it was an offshore bar (at least as old as Beaumont and occupying approximately its present position), and clay and silt filled the lagoon between it and the mainland.[4] For the formation composing this bar, which is correlative with one or more of the Quaternary units, the name Live Oak Bar formation is proposed. The Live Oak part of the name was taken from Live Oak ridge shown on the Aransas Pass topographic sheet.

About a mile southeast of Ingleside and 4 miles southwest of Aransas Pass, a Work Projects Administration party under the direction of Sellards (1940, pp. 1650–54) obtained a number of Pleistocene vertebrate and invertebrate fossils from a road-material pit in the formation (Fig. 14).

Southeast of Kingsville, Kleberg County, there is a deposit of sand partly cemented with calcium carbonate. It forms a ridge parallel with the coast line,

[3] A few years later Price (1936, p. 216) referred to this feature as "Live Oak ancient offshore bar" in a revised paper containing many additions and deletions but with the same title as the first.

[4] This differs from Price's theory that the bar moved inland from an offshore position to rest on the Beaumont (Price, 1933, p. 925).

extends a few feet above the surrounding plain, and is surrounded by clay and silt, probably Beaumont or Capitol in age. The deposit has been mined for road material. It may represent a buried sand bar with origin similar to that of Live Oak bar and the Recent offshore bar.

Reynosa caliche.—The name Reynosa was given to the caliche deposits at the town of Reynosa, Tamaulipas, Mexico, by R. A. F. Penrose, Jr. (1890, p. 63), and later extended by the writer to include all the caliche deposits of southwest Texas (1933, p. 467; 1937, p. 497). In this region of pedocal (carbonate-accumulating) soils, west of the 30 to 35-inch rainfall line, caliche is a secondary

FIG. 14.—Live Oak Bar formation near Ingleside, San Patricio County. Upper 2½-foot layer with loose sand removed from top is snail impregnated calcareous sand which overlies sandy clay. Many vertebrate fossils were excavated from lower part of pit by Work Projects Administration party.

accumulation of calcium carbonate in the soil and was deposited by downward moving waters (Weeks, 1933, pp. 472–76). Here there is insufficient rainfall to leach the calcium material from the soil and carry it away in solution as is the case in the region of pedalfer (non-carbonate-accumulating) soils on the eastward. In areas of caliche formation, calcium carbonate present in surface formations is taken into solution by rain water and is carried to the general level to which rain water penetrates the soil and is there precipitated. In this case, the upper layers of the soil during the normal process of soil development are leached of calcium carbonate. The depth of deposition may vary from a few inches to several feet (Fig. 15).

Much caliche formed after Uvalde time as indicated by its abundance on Uvalde and older formations; a little formed since Beaumont time; some is forming to-day. The older caliche deposits are dissected by erosion and over large areas the original soil cover is removed.

CORRELATION OF QUATERNARY DEPOSITS OF TEXAS COASTAL PLAIN WITH GLACIAL SCALE

Long-distance correlations from described sections of glacial deposits are difficult and subject to error. Nevertheless, some correlations are attempted (Fig. 16). In Iowa, Aftonian time was sufficiently long to permit formation of 8 to 9 feet of gumbotil on the Nebraskan drift and to leach upland gravels of calcareous material to a depth of 20 feet; Yarmouth time was sufficiently long to permit formation of 11 feet of gumbotil on Kansan drift and to leach upland

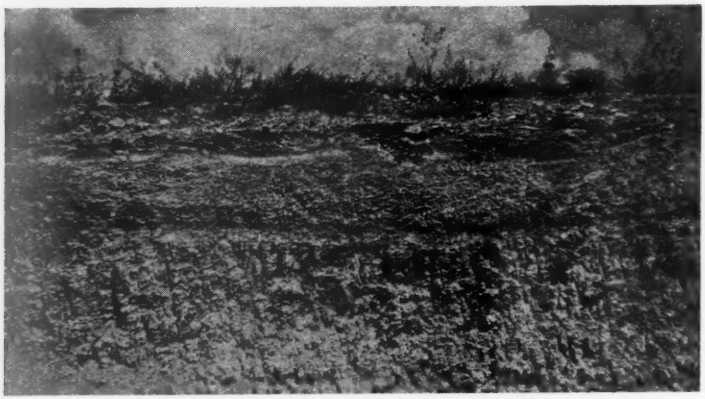


FIG. 15.—Caliche on and in upper part of Goliad formation (Pliocene) near Mathis, San Patricio County.

gravels to a depth of 30 feet; Sangamon time was sufficiently long to permit formation of 4 to 6 feet of gumbotil and to leach upland gravels to a depth of 12 feet; during Peorian time no gumbotil was formed but leaching extended to a depth of $5\frac{1}{2}$ feet; and during post-Wisconsin time leaching extended to a depth of $2\frac{1}{2}$ feet (Kay, 1931, pp. 425–66). In Texas, siliceous gravel and sand with no calcareous material constitutes the bulk of the deposits in the Willis, Gay Hill, and Bastrop Park deposits along Colorado River southeast of Travis County. These are in the zone of pedalfer (non-carbonate-accumulating) soils (Weeks, 1933, Figs. 3 and 4).

Limestone pebbles are present in Uvalde deposits beneath a leached upper surface in which only siliceous pebbles are present. The Iowan drift and loess is leached of calcareous material in its upper part.

On the basis of stratigraphic position and leaching, the Willis period of entrenchment and alluviation may be correlative with Nebraskan glacial and Aftonian interglacial ages; the Gay Hill, with the Kansan glacial and Yarmouth interglacial; the Bastrop Park, with the Illinoian glacial and Sangamon interglacial; and the Uvalde, with the Iowan and Peorian.

CORRELATION OF THE QUATERNARY DEPOSITS OF THE TEXAS COASTAL PLAIN WITH THE GLACIAL SCALE

AMOUNT OF WEATHERING OF GLACIAL DEPOSITS IN IOWA (FROM KAY, 1931)	GLACIAL & INTERGLACIAL AGES	QUATERNARY DEPOSITS IN VICINITY OF COLORADO RIVER
	RECENT	SAND BEACH & PRESENT STREAM DEPOSITS
		RIVERVIEW
		FIRST STREET
LATE WISCONSIN UPLAND GRAVELS LEACHED TO DEPTH OF 2.5'	↑ ICE RETREAT	BEAUMONT (SIXTH STREET)
	WISCONSIN 4 OR MANKATO	CAPITOL
	ICE RETREAT	ASYLUM
	WISCONSIN 3 OR CARY	
	ICE RETREAT	
	WISCONSIN 2 OR TAZEWELL	
NO GUMBOTIL CALCAREOUS MATERIAL LEACHED TO DEPTH OF 5.5'	PEORIAN	UVALDE (LIMESTONE PEBBLES LEACHED FROM UPPER PART OF DEPOSIT)
	WISCONSIN 1 OR IOWAN	
GUMBOTIL: 4-6' DEPTH OF LEACHING OF UPLAND GRAVEL: 12'	SANGAMON INTERGLACIAL	BASTROP PARK (SILICEOUS MATERIAL)
	ILLINOIAN GLACIAL	
GUMBOTIL: 11' DEPTH OF LEACHING OF UPLAND GRAVEL: 30'	YARMOUTH INTERGLACIAL	GAY HILL (SILICEOUS MATERIAL)
	KANSAN GLACIAL	
GUMBOTIL: 8-9' DEPTH OF LEACHING OF UPLAND GRAVEL: 20'	AFTONIAN INTERGLACIAL	WILLIS (SILICEOUS MATERIAL)
	NEBRASKAN GLACIAL	

A. W. WEEKS

FIG. 16.—Correlation of Quaternary deposits of Texas Coastal Plain with glacial scale.

The low level of Uvalde deposition along the coast indicates low sea-level during that period. Asylum perhaps was deposited during the latter part of Wisconsin time, and Capitol and Beaumont during a high sea-level. Therefore the

end of Beaumont time marks high sea-level (higher than to-day), probably registering maximum retreat of Wisconsin ice.

QUATERNARY GEOLOGIC HISTORY

While the Nebraskan ice cap accumulated in the north, there was some coastward tilting in Texas, lowering of sea-level, and erosion of interior Pliocene and older deposits. In the Coastal Plain erosion gullied the surface of the Goliad (Pliocene) and to-day inliers of Goliad are noted through "windows" in the Pleistocene deposits. Stream entrenchment probably occurred during formation of the ice cap and stream alluviation with rise of sea-level during retreat of the ice, so the end of Willis deposition may have been reached in Aftonian time. Perhaps during the following two glacial and interglacial ages, there were deposited, in like manner, the Gay Hill and Bastrop Park formations. Streams depositing these lower Pleistocene units carried coarsest material in the vicinity of and between Colorado and Guadalupe rivers. These streams probably obtained their material not only from denudation of the central Texas area, but also from erosion of the Pliocene débris apron spread eastward from the Rocky Mountains. Toward the southwest in Bee, Live Oak, Jim Wells, and Nueces counties, streams hemmed in by the Edwards Plateau deposited fine sands, silts, and clays. Standing above the general level of deposition throughout the Quaternary was the Reynosa-covered region situated between Nueces River and Rio Grande, which to-day, rising to an elevation slightly greater than 900 feet in southeastern Webb County, stands above the general level of the country and may be called the Reynosa cuesta.[5]

In the Texas Coastal Plain, all evidence of the presence of a stream at the general location of the Rio Grande during the early Pleistocene seems to have been obliterated during Uvalde time.

The distribution of gravels in northeast Maverick County suggests there once existed a stream connection from the Rio Grande to the Nueces.

Perhaps during Uvalde time the Pecos River, cutting through the Cretaceous barrier in West Texas and working headward, removed a large part of the sedimentary cover in southeastern New Mexico.

During low sea-level streams of Uvalde time cut their channels deeply into the surface of the Coastal Plain and erosion of the Edwards Plateau was extensive as indicated by the amount of limestone and chert-pebble débris spread across the Coastal Plain. Perhaps also there was uplift in the interior and disturbance along fault zones resulting in release of much water having its source in the Lower Cretaceous aquifer of central Texas. Probably during this time the caves and sink holes of the Edwards Plateau were formed.

[5] This region is bordered on the west by the Bordas (Dumble, 1903, p. 918), or Reynosa, escarpment. From the crest of this escarpment near Torrecillas (Oilton), the surface slopes gently eastward to a secondary north-south topographic rise in southeastern Webb County, known as the Bruni escarpment, from which the surface again slopes eastward to the coast. This Pliocene-covered region, capped with Reynosa caliche, stands as a great erosion feature in a region of low rainfall (about 20 inches per year). It has been called the Reynosa plateau (Dumble, 1894, p. 562) and the Reynosa Plain (Deussen, 1924, p. 8).

The end of this period, like the end of many cycles of sedimentation, was far quieter than the beginning, for silts and clays mark the final sedimentary deposits of Uvalde time, especially in southwest Texas.

Late in the Pleistocene a blanket of caliche formed in the upper part of calcareous formations located west of the approximate 32-inch rainfall line.

Along the Colorado, the scattered granite pebbles in the Uvalde are forerunners of the dominant granitic sediments of Asylum and Capitol time which indicate downcutting into the granites of the Llano uplift. With Beaumont time there was deposition, throughout the region under discussion, of the clay and silt type of material which, in general, continues to the present. On the southwest, however,

FIG. 17.—Miniature delta in road material pit near Papalote, Bee County.

where streams such as the Guadalupe, Nueces, and Rio Grande head in or pass through the vast Cretaceous limestone section, clay and silt deposition occurred earlier.

The offshore bar along the coast, consisting of Padre, Mustang, St. Joseph, and Matagorda islands and Matagorda Peninsula, belongs to the Sand Beach and present period of sedimentation. Landward from it is Live Oak bar, which probably was present during Beaumont time and in date of origin probably belongs to the Capitol-Beaumont period of high sea-level. Another sand deposit, perhaps representing a still older bar nearly buried by clay and silt of Beaumont or older age, lies 5 miles southeast of Kingsville, Kleberg County.

Some of the sedimentary processes, both past and present, in the Gulf Coast are illustrated in Figure 17. The walls of the pit consist largely of Willis sand and clay. Calcareous Goliad clay is exposed at, and a few feet above, the floor of the pit. At time of rainfall water flowed into the pit, cut channels across the floor, and formed deltas. These streams discharged into a pond which occupied the low fore-

ground. An older stage of deposition is represented by higher ground above the latest delta.

With low water level in the pit, a rain could cause a channel to be cut across the delta and initiate a lower level of sedimentation. A rain following high water level would permit delta building on the earlier deposits. Imagine a number of streams, each building a delta with somewhat different type of sediments, coastward tilting, climatic changes, and a fluctuating sea-level, and a view is presented of some of the sedimentary processes in the Gulf Coastal Plain during Quaternary time.

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OAKVILLE, CUERO, AND GOLIAD FORMATIONS OF TEXAS COASTAL PLAIN BETWEEN BRAZOS RIVER AND RIO GRANDE[1]

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ABSTRACT

The geologic section, which is mapped and described, is as follows.

Pliocene
  Goliad formation
Miocene
  Fleming group
    Cuero formation
    Oakville formation

The name Cuero is proposed for a formation containing reddish-colored clays exposed in a belt from Live Oak County to Lavaca County, Texas.

INTRODUCTION

In this paper the Fleming group of Miocene age (Oakville and Cuero formations) and the Goliad formation of Pliocene age, of the Texas Coastal Plain between Brazos River and Rio Grande, are mapped and described. For the upper part of the Fleming group in the central part of the area under discussion, from Live Oak County to Lavaca County, the name Cuero is proposed for a formation containing reddish-colored clays. This name was reserved with Alice S. Allen and later checked with M. Frances Willoughby, both of the United States Geological Survey, and was found to be available for use.

FLEMING GROUP

Kennedy (1892, pp. 62–63) applied the name Fleming, taken from the station of Fleming (now Hampton) in Tyler County, Texas, to beds lying above the Jackson group and below Pleistocene sands and clays. The beds to which Kennedy applied the name Fleming therefore include the present Catahoula formation as well as younger Miocene beds. Whether overlap of the Pleistocene east of the Brazos is sufficient to exclude all of the Goliad formation from his Fleming can not be stated since the writer has not mapped the surface geology of the region covered by Kennedy's paper.

In Louisiana, A. C. Veatch (1906, pp. 43–44) applied the name Fleming to beds lying above the Catahoula and below the "Lafayette" gravel and sand (Willis age and younger).

A description of the Fleming east of Brazos River and a discussion of its subsurface relations is given by A. C. Ellisor (1944, pp. 1360–63).

In this paper Fleming is considered a group name including both the Oakville

[1] Manuscript received, June 4, 1945.

[2] Sun Oil Company.

and Cuero formations. It thus embraces the Miocene section above the Catahoula formation.

OAKVILLE FORMATION

Name.—The name Oakville was given by Dumble (1894, pp. 556–59) to beds exposed in the vicinity of the town of Oakville in Live Oak County. Later he discussed these beds more fully (1903, pp. 956–76), and included in the Oakville the entire section between the underlying Catahoula formation (E. T. Dumble's Frio) and overlying Pliocene beds now known as the Goliad formation. In this paper the Oakville formation includes the same rocks assigned to it by Dumble,

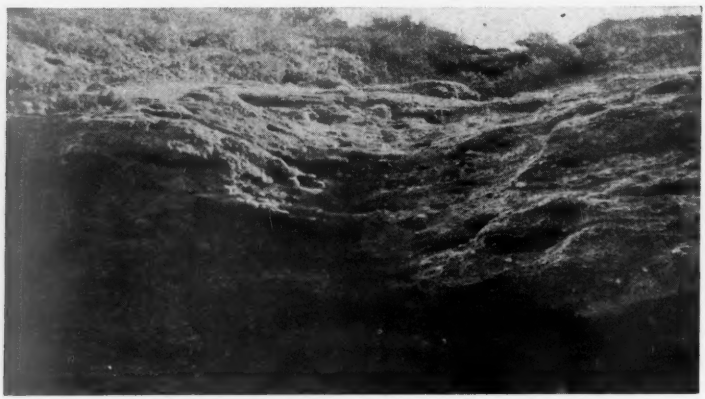

FIG. 18.—Conglomerate of limestone and siliceous pebbles in Oakville formation. Four miles south of Hochheim near U. S. Highway 77, De Witt County.

with the exception that the upper part which contains much material of red and pink color in the central part of the region is segregated and discussed separately under the name Cuero.

Southeastward from Oakville in Live Oak County much of the Cuero formation is covered by Pliocene or Pleistocene deposits and perhaps for this reason was not recognized by Dumble (Fig. 1).

Areal extent.—Oakville beds are present along the Rio Grande in Starr and Hidalgo counties. Northward, from southern Starr County to northern Duval County, the Oakville formation is overlapped by the Goliad. From Duval County northeastward to the Brazos River and beyond, the Oakville can be followed continuously above the Catahoula formation (Fig. 1).

Lithology.—The Oakville formation consists mostly of calcareous clays and fine to coarse-grained cross-bedded sandstones, all gray to yellow or buff in color. In local areas the clays are reddish and resemble the overlying Cuero clays. The formation also contains reworked Cretaceous shell fragments and beds and lenses

of gravel made up of chert, igneous rock, quartzite, fossil wood, and limestone, the last well rounded and abundant (Figs. 18 and 19). Sandstones near the base form a prominent escarpment across the region above Oakville and Catahoula clays.

Coastward in the subsurface non-marine beds are intercalated with marine Miocene sands and clays. These sands are productive of oil and gas on some salt-dome structures.

Stratigraphic and structural relations.—The Oakville formation unconformably overlies the Catahoula formation and apparently is conformably overlain by the Cuero formation. On the San Marcos arch in Gonzales and Lavaca counties, the

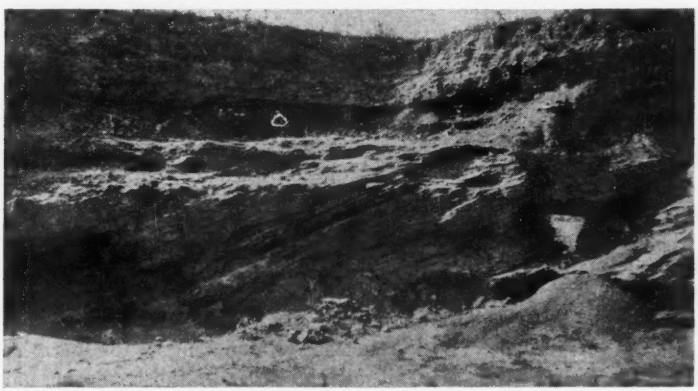

FIG. 19.—Oakville sandstone and clay with calcareous nodules. Pit on west side of Highway 95, directly south of Shiner, Lavaca County.

lower Oakville clay section, underlying the Moulton sandstone (Renick, 1936, Pls. 3, 4, and 5), overlaps a considerable part of the Catahoula.

Because of the cross-bedded nature of the formation, it is difficult to obtain accurate dip and thickness for the Oakville but in Karnes and DeWitt counties, it is believed to dip coastward 50 to 60 feet per mile and to have a thickness of about 500 feet. The formation thickens northeastward.

Age and fauna.—Between Oakville and Fort Merrill (about 8½ miles below George West) Dumble (1903, p. 957) collected *Merychippus insignis* Leidy, *Merychippus* (*Protohippus*) *perditus* Leidy, *Merychippus* (*Protohippus*) *placidus* Leidy, and *Aphelops meridianus* Leidy, all of which were identified by Cope who believed them to be upper Miocene in age. Since the exact locality from which these fossils were taken is not given, no statement can be made regarding the position in the Oakville section of the beds from which the fossils were obtained. Whether some came from the section assigned to the Cuero formation is not known.

Northeast of Brazos River, O. P. Hay (1915, pp. 1–19) described several new

species from the J. Garvin farm 2 miles north of Navasota, Grimes County, and after comparing his data with those previously given by Matthew (Dumble, 1915, p. 472), for vertebrates collected by C. L. Baker from the same general locality, he concluded that the formation from which the fossils came is upper Miocene.

Dumble (1818, p. 237) quoted Matthew as concluding that the Navasota vertebrates are of the same age as some collected from $1\frac{1}{4}$ miles north of Cold Spring, San Jacinto County.

At a locality called Dripping Springs, about $1\frac{1}{2}$ miles northeast of Borden and 9 miles west of Columbus, Colorado County, T. L. Bailey (1923, pp. 81–82) found one molar and two front teeth of *Merychippus* (*Protohippus*) *perditus* Leidy.

From Fleming beds (northeastward equivalent of the Oakville) near Burkeville, Newton County, H. B. Stenzel (1941, p. 1000) collected vertebrate and invertebrate fossils which he considers to be upper Miocene in age.

In summary the vertebrate fossils from the Burkeville, Cold Spring, Navasota, Borden, and Oakville localities, all from within the Oakville or Fleming section, are reported to be Miocene in age, probably upper Miocene.

Origin.—The cross-bedded character of the Oakville sands and the rapid alternation from fine to coarse deposits is suggestive of a deltaic deposit. Coastward the formation contains marine fossils.

The abundance of Cretaceous shell fragments and pebbles and cobbles of limestone interbedded and intermixed with calcareous clays suggests considerable uplift and disturbance in the Cretaceous section fringing the updip part of the Coastal Plain. The scarce intermittent pinkish and reddish coloring noted in the Oakville indicates a source for red-colored material but it was not until Cuero time that an abundant source of this material was tapped.

CUERO FORMATION

Name.—The name Cuero, taken from a city in DeWitt County, is here proposed for the predominately red, pink, green, and gray section of clays and sandstones lying above the Oakville formation and below the Goliad formation. In Bee, Karnes, and DeWitt counties, it is identical with the section assigned to the Lower Lagarto by Weeks (1933, pp. 457–60) and is a part of the section assigned to Lagarto (emended) by F. B. Plummer (1933, pp. 740–41).

The reasons for discarding the name Lagarto (emended) follow.

1. The name Lagarto was given by Dumble (1894, pp. 559–60; 1903, pp. 973–76) to beds of Pliocene age on Lagarto Creek in Live Oak County and Penitas Creek in Jim Wells County which later were included in the formation assigned to the Goliad.

2. The type section assigned to Lagarto (emended) by Plummer (1933, pp. 740–41), which is located directly west of Brazos River on the Brenham-Hempstead road, has the character of the Oakville: tan, gray, brown, and yellow sandstones, commonly cross-bedded, and clays.

3. Fossils obtained from sections mapped as Lagarto (emended), Oakville, and Fleming were determined to be Miocene in age, largely upper Miocene. (See discussion under Oakville.)

Areal extent.—The line separating Oakville and Cuero deposits parallels the strike of the older formations through Bee, Karnes, and DeWitt counties (Fig. 1). East of DeWitt County, it loses its parallelism with the base of the Oakville and trends north of Yoakum, north of Sweet Home, and south of Hallettsville, all in Lavaca County, and through the town of Columbus in Colorado County. The

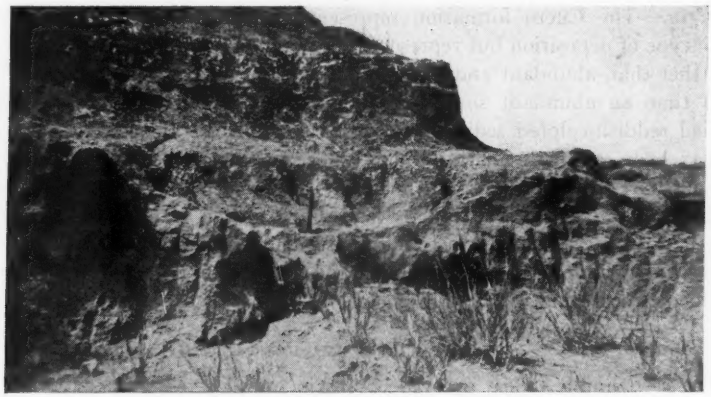

FIG. 20.—Red calcareous Cuero clay and yellowish brown sand and sandstone. Pit northeast of Hallettsville, Lavaca County.

Cuero type of deposit is still recognizable on the Colorado at Columbus, but northeastward it is lost at the surface.

The disappearance of the Cuero formation northeastward may be explained by a change in facies from the Cuero type into the Oakville type or by overlap of the Goliad on the Oakville, probably the former.

Lithology.—The Cuero formation is differentiated from the Oakville by its variegated color—red, pink, green, gray, brown—and mottlings of these colors and by marked decrease of conglomerates. The colors in the overlying Goliad are much the same as in the Cuero but the Goliad, like the Oakville, contains considerably more conglomeratic material. In general, the Cuero represents a quiet phase of deposition as compared with those of the other two, and its clays are generally described as being more plastic than the more calcareous clays of the Goliad. Calcareous nodules are common. Sandstones which are intercalated with clays range from fine to coarse and from pink to brown to gray (Fig. 20).

Stratigraphic and structural relations.—The section assigned to the Cuero is believed to conformably overlie the Oakville formation and to dip coastward at approximately the same rate, or 50 to 60 feet per mile. It is overlain uncon-

formably and with considerably less dip by the Goliad formation. The Cuero formation thickens coastward; in the area of its outcrop it is believed to have a thickness of about 350 feet. It probably is only an upper part of a continuous series of deposits beginning in Oakville time.

Age and fauna.—As far as the writer is aware no fossils, either vertebrate or invertebrate, have been obtained from beds here referred to as Cuero. However it is possible that some of the vertebrate fossils collected between Oakville and Fort Merrill (see discussion under Oakville) came from the formation here assigned to Cuero and if so would determine its age as upper Miocene.

Origin.—The Cuero formation represents a continuation of the Oakville deltaic type of deposition but represents a quieter phase since conglomerates are few rather than abundant and much of the section is clay. At the beginning of Cuero time an abundant source of red coloring material was tapped which supplied reddish-colored sediments upward through the Pliocene. Triassic and Permian beds of North-Central and West Texas may have been denuded of a sufficient part of their Cretaceous cover at this time to furnish a source of red coloring material. Perhaps also there was a source of iron in the Rocky Mountains since the Pliocene sediments now preserved in the Llano Estacado of West Texas and which were spread eastward from the Rockies in Pliocene time also are described as containing clays of brown color (Plummer, 1933, pp. 771–72).

GOLIAD FORMATION

Name.—Dumble (1894, pp. 559–60; 1903, pp. 973–76) divided the Pliocene section in the vicinity of the Nueces River in Live Oak and Jim Wells counties into two divisions. To the lower division with lithology much like that of the Oakville formation of Miocene age, he gave the name Lapara taken from Lapara Creek and the now abandoned Lapara post office in Live Oak County; to the upper division he gave the name Lagarto taken from the settlement of Lagarto and Lagarto Creek in Live Oak County. For Dumble's description of these sections, reference is made to his 1903 paper.

Deussen (1924, p. 100) recognized the type locality of the Lagarto formation but in his sections and on his geologic map, he included in his Lagarto lower beds now believed to be Miocene in age.

Weeks (1933, pp. 457–60) included the Lagarto and Lapara beds of Dumble under the name Upper Lagarto, and to the underlying section of red clays and sandstones, then generally known as Lagarto from the earlier work of Deussen, he gave the name Lower Lagarto. (In the present paper, the Lower Lagarto is assigned to the Cuero formation.)

The name Goliad was first used about 1928 by geological field parties for a mappable unit of beds composed largely of sandstone exposed in the vicinity of Goliad, Goliad County. At that time and for several years later, many of the field workers apparently were unaware that the Goliad beds composed a part of the section previously named Lagarto by Dumble.

During the years 1932 and 1933, the name Goliad was accepted by the San Antonio Geological Society, the Houston Geological Society, the Texas Bureau of Economic Geology, and the United States Geological Survey as a formation name to cover the Lagarto and Lapara formations of Dumble. These now may be considered members of the Goliad formation. Later when fully mapped, Lapara and Lagarto may return to formation status and Goliad become a group name.

Even though the Lapara and Lagarto divisions of Dumble have not been differentiated on the geologic map, the two are shown in the legend on the geologic map for the following reasons.

1. There is a lithologic difference between Dumble's Lagarto and Lapara. In general the Lagarto is more consolidated, more calcareous, and contains more sugary-textured sandstones than does the underlying Lapara.

2. In certain areas and particularly on the Reynosa cuesta of southwest Texas, from central Duval County to the Rio Grande, divisions of the Goliad have been mapped by the writer (Weeks, 1937, p. 495). A section of sand and gravel at the base of the Goliad, ordinarily unconsolidated but in some places cemented into a firm siliceous conglomerate where it overlaps older beds sufficiently to rest on the Catahoula, is considered Lapara; the upper section consisting principally of red calcareous clay is considered Lagarto (Fig. 21). However, more work is necessary to determine the full relations of these units to the Lapara and Lagarto divisions of Dumble in Live Oak County.

Areal extent.—The Goliad formation is exposed from the Rio Grande northward and northeastward in a continuous belt to and beyond the Guadalupe River. In southeastern De Witt and Lavaca counties much of the Goliad is covered by Willis and younger formations. Farther northeastward only a few exposures were noted through "windows" in the overlying Pleistocene deposits. Two of these are: 8 feet of gray Goliad sandstone and conglomerate at the west end of Colorado River bridge on the Eagle Lake-Altair highway, Colorado County; and 30 feet of calcareous Goliad sandstone on the west side of Brazos River about 500 feet above the San Felipe ferry crossing, Austin County. Another exposure which may be Goliad, even though it is not typical of that formation (it is not very calcareous), is present along Brazos River north of Richmond, Fort Bend County. It consists of 15 to 20 feet of interbedded sandstone and red clay. This exposure has more of the aspects of Pliocene than of Pleistocene formations seen elsewhere by the writer; yet it is not typical of either. If Goliad it is an exceptional exposure this far coastward.

In the summer of 1940 the writer examined cores from two test holes drilled west of Houston between Alief and Clodine, Harris and Fort Bend counties, which were supervised by the United States Geological Survey, Ground Water Division.[3] The following generalized section is pieced together by using some data from these tests.

[3] For permission to examine the cores the writer is indebted to W. N. White in charge of the

	Depth in Feet
Goliad clay with calcareous nodules and brown sand. (First sample at 190 feet)	190– 375
Goliad gray calcareous sand and red clay	375– 700
No samples	700– 704
Fine gray to pinkish sandstone. (Has appearance of Cuero)	704– 705
No samples	705–1,004
Fine gray to brown sand and brown, tan to gray calcareous clay. (Appears like Oakville)	1,004–1,014
No samples	1,014–1,306
Red, pink, brown, and green clay with white calcareous nodules and gray calcareous fine salt and pepper sand. (Has appearance of Cuero or Oakville)	1,306–1,325

The main water supply at Houston and vicinity comes from the Goliad formation and the Fleming group.

Lithology.—The Goliad formation is composed of red, pink, orange, and gray clays, white to gray sugary sandstones, and conglomerate beds containing pebbles of limestone, gray and black chert, and fossil wood, all commonly interbedded with sand or intermixed with clay balls (Figs. 22, 23, and 24). A characteristic feature of the Goliad group is the large amount of calcareous material which accounts for the thick beds of caliche ordinarily found in the upper part of the Goliad section exposed in cuts and pits in southwest Texas (Fig. 15).

Stratigraphic and structural relations.—The Goliad formation unconformably overlies the Cuero formation and in turn is overlain unconformably by Willis or younger Pleistocene. On the Reynosa cuesta, as in southeastern Webb County where there is considerable altitude, the Goliad formation extends a sufficient distance westward to cover part of the Catahoula formation. It dips coastward about 25 feet per mile and near the downdip edge of its outcrop probably reaches an average thickness of about 500 feet.

Age and fauna.—About 6½ miles northeast of Beeville, Bee County, and in the formation exposed on Medio Creek, about 2,000 feet east of where the road, which passes through the John R. Scott land, Juan de Dios Molina Survey, crosses Medio Creek, H. T. Richardson found the jaw bone and one tooth of a rhinoceros pertaining to the genus *Teleoceras* and tentatively referred to the

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Austin office, and Nicholas A. Rose, in charge of the Houston office of the Ground Water Division.

The following comment is made regarding correlations on Plate 11 and pages 146 and 147 in *U. S. Geological Survey Water-Supply Paper 889-C*, "Ground Water Resources of the Houston District, Texas," by W. N. White, N. A. Rose, and W. F. Guyton, published in 1944.

White *et al.* divided the section encountered in water wells into six zones. As a working hypothesis the following suggested correlations are made, based on the Goliad and Fleming samples examined. The uppermost zone, 6, is probably the clay facies of the Quaternary (Beaumont) and the next lower, 5, the sand facies of the Quaternary (Willis-Capitol). Zone 4 is questionable. The upper part of zone 3 appears to be Goliad since the samples from depths between 190 and 700 feet, obtained from test wells between Alief and Clodine, came from this zone. The lower part of zone 3, and zones 2 and 1 probably are Fleming.

On White *et al.* section B-B′ (Clodine-Houston), Plate 11, zone 3 is shown incorrectly as cropping out between Alief and Clodine. It does not crop out as shown, but is covered with a mantle of Quaternary. Likewise zone 3 of Section A-A′ (Hempstead-Houston), Plate 11, does not crop out between Hempstead and Cypress as shown on the section, but is covered with a mantle of Quaternary sand, gravel, and sandy clay (Willis-Capitol).

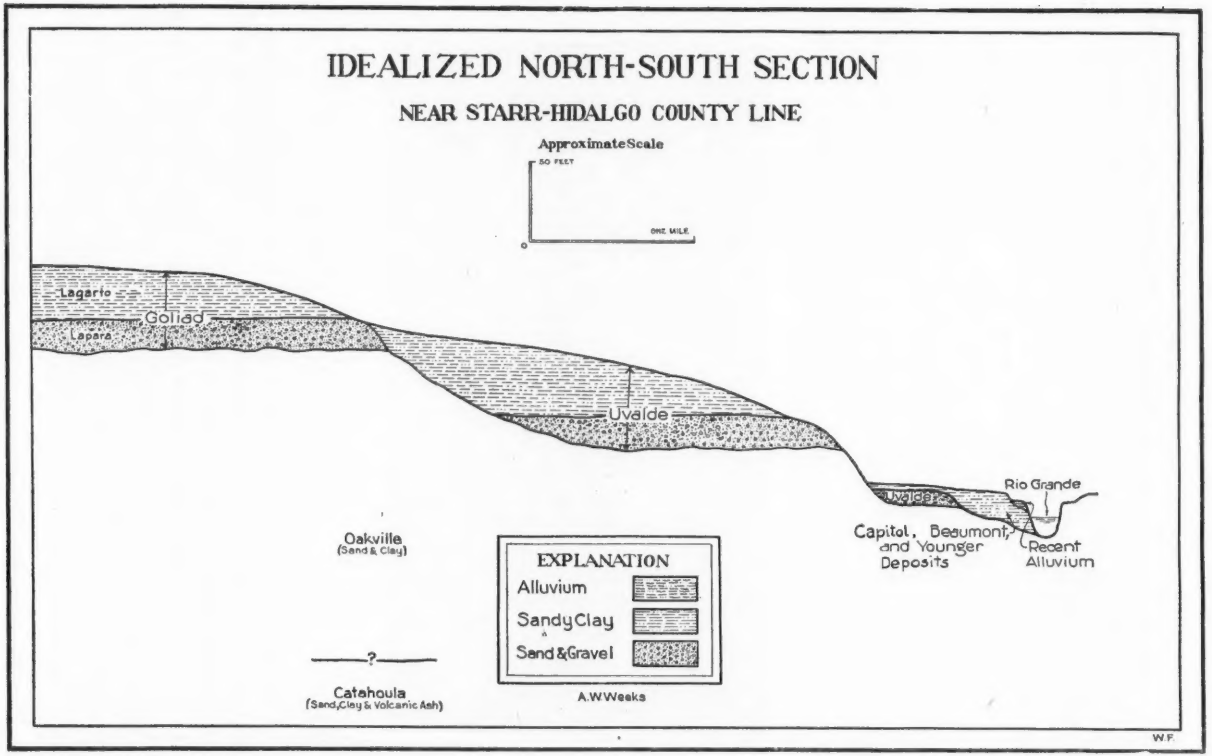

FIG. 21.—Idealized north-south section near Starr-Hidalgo County line.

species *fossiger* of Pliocene age by Gilmore of the United States National Museum. About 2 miles S. 65° E. of Normanna, Bee County, in a tributary of Medio Creek, and in the Thomas Duty Survey, some vertebrates were collected which Richardson sent to C. L. Camp of the Museum of Paleontology, University of California, at Berkeley, who reported as follows.

> The following forms are represented by somewhat fragmentary remains:
>
> *Hipparion* cf. *venustum*
> *Pliohippus* cf. *interpolatus*
> *Aphelops* sp.
> *Camel* gen. et sp. indet.
>
> Similar horses are found in the Clarendon and Goodnight horizons of the Panhandle Tertiary of Texas, and it is our opinion that the age of the deposit from which your material was secured is Lower to Early Middle Pliocene.

In the formation exposed on Medio Creek, Bee County, about 3 miles south-

FIG. 22.—Goliad sandstone and calcareous clay. Road cut at east side of Lagarto Creek bridge, ¼ mile west of settlement of Lagarto, Live Oak County. Type locality of Lagarto formation of Dumble.

east of the aforementioned locality and about 2 miles north of the Beeville-Goliad highway, Richardson found teeth which were sent to Gidley of the United States National Museum, who reported as follows.

> The three teeth are upper cheek teeth of the left side of a small species of the *Hipparion* group of three-toed horses. They pertain to a single individual, including premolar 4 and the first and second true molars, but they belong to an old individual and are worn too near their bases to be certain of specific determination. It may be said, however, that they are about the size of the corresponding teeth of *Hipparion ingenium*, a Florida species of Pliocene age, and may be referred tentatively to that species.

A Pliocene mastodon (Sellards, 1940, pp. 1659–64). *Gnathabelodon buckneri* Sellards, was obtained from Goliad beds beneath fossiliferous Pleistocene terrace

FIG. 23.—Goliad section of clay and sandstone. Road cut on State Highway 9, slightly more than ½ mile northwest of Swinney Switch, Live Oak County. Note wedge of red clay in left and central part of picture.

material at an excavation along Blanco Creek on the E. H. Buckner ranch about 12 miles east of Beeville, Bee County, Texas.

The following invertebrate fossils, identified by W. B. Marshall (1929, pp. 1–6) and reported to be extinct to-day, were collected by I. K. Howeth from beds presumably Goliad in age along the banks of Guadalupe River, south-central DeWitt County.

Pliconaios popenoei Marshall
Eonaias reynosenica Marshali
Antediplodon dewittensis Marshall
Polygyra myersi Marshall

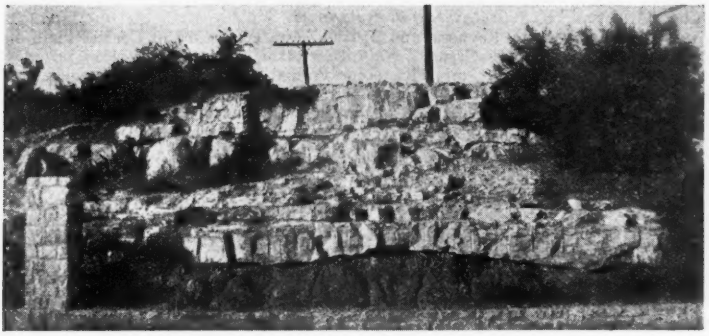

FIG. 24.—Gray Goliad sandstone and green and red clay. Highway underpass in southern part of town of Goliad, Goliad County.

Origin.—The more gentle dip of the Goliad formation compared with the Fleming group indicates coastward tilting prior to Goliad deposition. The conglomeratic material in the Goliad may indicate renewed disturbance in the Balcones and other fault zones, but much of the Goliad material probably was derived from the reworking of deposits of the Fleming group. Additional material was carried in, perhaps as far as from the Rockies, for at this time a Pliocene débris apron was spread eastward from the Cordillera over much of Texas, New Mexico, and adjoining area, some of which still remains in the Llano Estacado. The waters which deposited these sediments carried much calcium carbonate in solution which was precipitated as sedimentation proceeded.

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BALCONES, LULING, AND MEXIA FAULT ZONES IN TEXAS[1]

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ABSTRACT

The Balcones fault zone crosses the San Marcos arch and is located between the comparatively flat dip of the Edwards Plateau and the more steeply dipping beds of the Coastal Plain. It is composed principally of faults with downthrown side on the southeast. The throw on faults of this zone approximates 1,200 feet in northwestern Bexar County.

The Luling fault zone lies coastward from the Balcones fault zone and is composed principally of faults with downthrown side on the northwest. In Caldwell County along San Marcos River a total throw of more than 1,500 feet is indicated by faults of the Luling type.

The Mexia fault zone lies eastward and southeastward from the Luling zone and is characterized by faults with downthrown side on the southeast and by faults with downthrown side on the northwest. Both commonly occur with a graben of varying width between them. This zone of faults extends from north and northeast of Mexia, Limestone County, southwest through parts of Milam Burleson, Lee, Bastrop, Fayette, Gonzales, and probably through parts of De Witt, Karnes, Goliad, Bee, Live Oak, and Duval counties. Major movement along these faults probably occurred in late Catahoula or early Oakville (Miocene) time, thus affecting sedimentation of this period. Minor faults are present in Pliocene and basal Pleistocene formations. Some Recent movement is recorded.

INTRODUCTION

In this paper the Balcones, Luling, and Mexia fault zones are outlined and are discussed with reference to their age and to the geologic history of the Coastal Plain deposits.

Published data indicate the Luling and Mexia faults belong to a single zone (Lahee, 1929, p. 306, Fig. 1; Sellards, 1934, pp. 62–66; The Committee on Tectonics, 1944). The writer believes the two are distinct and that the Mexia zone passes to the east of and down dip from the Luling zone (Figs. 1 and 25). The difference between these two zones was first recognized by the writer 15 or more years ago when doing geological work in Texas. The throw of the faults of both the Balcones and Luling zones is greatest across the San Marcos arch. These two zones appear to be more closely related, since one is complementary to the other, than is either of these zones with the Mexia zone.

Figure 25 is intended to indicate the location of each zone discussed rather than to show all of the faults in each zone. It is not intended to show all faults and fault zones in Texas. In southern and eastern Texas there are many faults not shown on the map. Some appear to belong to a definite zone; others do not.

BALCONES FAULT ZONE

Extending through the vicinities of the towns of Georgetown, Austin, San Marcos, New Braunfels, and some distance north of the towns of San Antonio, Hondo, and Uvalde is the Balcones fault zone with downthrown side principally on the southeast.

[1] Manuscript received, June 4, 1945.

[2] Sun Oil Company.

This zone of faults is located between the comparatively flat dip of the Edwards Plateau and the more steeply dipping beds of the Coastal Plain, and crosses the San Marcos arch, a broad nose which plunges southeastward from the Llano uplift. In the vicinity of Austin, Travis County, the total throw across the Balcones zone of faults approximates 900 feet; in northwestern Bexar County, 1,200 feet; in northeastern Uvalde County, 500 feet; and in southwestern Uvalde County, 200 feet. In Kinney County the Balcones zone of faults dies out.

LULING FAULT ZONE

The Luling fault zone lies coastward from the Balcones zone and is composed principally of faults with downthrown side on the northwest. Examples of this zone are: (1) the Staples, Larremore (along which the Larremore oil field is located), and Lytton Springs line of faults in Guadalupe, Caldwell, and Bastrop counties; (2) the Luling fault in Guadalupe and Caldwell counties along which the Luling oil field is located, and which extends northeastward across Caldwell County and into Bastrop County; (3) the Darst Creek-Salt Flat line of faults along which fields of these names are located in Guadalupe and Caldwell counties; and (4) the Somerset and Alta Vista faults in Atascosa and Bexar counties. All of these faults have considerable length. The average throw approximates 450 feet.

In Caldwell County along San Marcos River, a total throw of more than 1,500 feet is indicated on faults of the Luling zone. The faults of this zone have the greatest throw and are most numerous from Travis and Bastrop counties southwest through Bexar County, thus crossing the San Marcos arch.

MEXIA FAULT ZONE

Farther down the dip than the fault zones described above is the Mexia zone of faults characterized by faults with downthrown side on the southeast and by faults with downthrown side on the northwest. Both faults commonly occur together with a graben of varying width between them. In the Mexia area, the name Tehuacana has been given to faults on the northwest side of the graben (Lahee, 1929, p. 304). The Mexia zone of faults extends from the vicinity of Mexia, Limestone County, northeastward and eastward around the Tyler basin. Faults in southwestern Arkansas probably are a part of this zone. From Mexia southwestward this zone of faults extends far into South Texas and offsets down the dip at various points. At Mexia, Midway beds at the surface are cut by the faults; in Lee County, Mount Selman; in Bastrop and Fayette counties, Cook Mountain and Yegua; and in Gonzales County, Yegua and Jackson.

The zone of faults extending southwest through parts of DeWitt, Karnes, Goliad, Bee, Live Oak, and Duval counties may be part of this zone. Representative faults are those along which oil and gas have accumulated in northern Bee County in the vicinity of Pettus. Considering all of these faults as belonging to the Mexia zone, in Texas alone the length of the zone is over 500 miles.

FIG. 25.—Balcones, Luling, and Mexia fault zones in Texas.

In the region of Mexia many of the faults along which oil and gas production is obtained from the Woodbine are *en échelon*, with the south end of the fault at the north passing west of the north end of the fault at the south. This causes closure at the south end of each of the fields. At the north end of these fields the strike of the beds and the strike of the faults converge, thus effecting closure in this direction. There is a structural high in the region of Mexia, and south of this high the strike of the beds and the strike of the faults tend to converge at the south end of each fault structure and tend to diverge at the north end. This lack of effective north closure, plus absence of Woodbine sand, probably is the reason for barren structures on the south toward the Falls County regional low.

PROBABLE DATES OF MOVEMENT ALONG FAULT ZONES

The writer knows of no evidence to indicate the fault zones described above are different in age. That is, it is quite possible major movements along each may have occurred at approximately the same geologic epoch. The writer believes there was major movement along these faults in late Catahoula (Oligocene or Miocene)[3] or early Oakville (Miocene) time, thus affecting sedimentation of this age. The abundance of Cretaceous shell fragments and pebbles and cobbles of limestone interbedded and intermixed with calcareous Oakville clays suggests considerable uplift and erosion in the Cretaceous section fringing the updip part of the Coastal Plain.

Some earlier movement is registered at the end of the Lower Cretaceous, and information regarding movement later in the Cretaceous has been published (Collingwood and Rettger, 1926, p. 960; Lahee, 1929, pp. 227, 352; Collingwood, 1930, p. 1196). Nevertheless, extensive surface and subsurface work throughout the area reveals that any large subsurface fault in Cretaceous beds is indicated in outcropping lower Eocene (Midway and Wilcox beds) by a large surface fault. Data obtained from diamond core holes to the Navarro formation and oil tests to the Woodbine along the North Currie fault, Navarro County, reveal that displacement in the Midway of 400 feet is the same as that in the Austin chalk and the Woodbine (Lahee, 1929, pp. 345–46).

There are large surface faults in Claiborne and Jackson beds along the Mexia zone, but sufficient subsurface data are not available to the writer to determine the relation in throw between the surface and older subsurface beds. In the Millican fault zone area of Brazos County, a surface fault with a throw of about 200 feet in surface beds of Catahoula and Jackson age is no larger in the subsurface Claiborne (Renick, 1936, p. 94).

Further evidence of major movement in late Catahoula or early Oakville time is found in the fact there is considerable difference in throw in some faulted surface beds in Pliocene and younger formations and the throw in older beds.

[3] There is disagreement as to whether the Catahoula formation is Oligocene or Miocene in age. In the subsurface it appears equivalent to the Frio formation.

For example, in the Bee County area small surface faults in the Goliad formation with throw probably less than 50 feet overlie subsurface faults in the Jackson group with throw of several hundred feet.

In Starr and Hidalgo counties, evidence of small post-Pliocene movements, both faulting and folding, is present in the Goliad (Weeks, 1937, pp. 493, 499). In East Texas, Doering (1935, pp. 677, 683) and others report evidence of post-Willis movement. Perhaps such movement occurred during Uvalde time when a great amount of limestone pebble débris was deposited coastward from the Edwards Plateau.

That some movement continued to the present is evidenced by the so-called "breastworks" at the surface trace of the faults of the Mexia zone in the northern part of Lee County in the general vicinity of Lexington where in places the upthrown side of the fault stands a few feet higher at the surface than the downthrown side.

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GEOLOGICAL TERMINOLOGY IN CLASSIFICATION OF OIL AND GAS ACCUMULATIONS[1]

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INTRODUCTION

Methods of exploration for oil and gas are best developed and applied if concrete types of accumulation are recognized and classified. From the earliest development of the oil industry great importance has been attached to all problems involving the classification of the main types of oil and gas provinces, fields, and individual accumulations. However, there has been no widely accepted universal classification; there is not even a unified opinion about the basic terminology widely used, both in geological practice and in the extensive publications on oil and gas. In studying the main types of elementary oil and gas accumulations, it is found that the same terms and concepts are given different use and meaning, not only in the works of different geologists, but also in the works of any one geologist.

In working on the definitions and terminology necessary for the classification of oil and gas accumulations, an attempt has been made to establish the origin of the terms in use. Consideration is given to prevailing modern conceptions of each term in its relation to others.

The definitions and statements offered in this article should be subjected to wide criticism among all petroleum geologists.

I. OIL-BEARING ROCKS AND SOURCE ROCKS

EARLIEST CONCEPTIONS

In the earliest development of the oil industry, during the first years of drilling when ample data concerning the geological structure of oil fields had not yet been gathered—all ideas of the conditions of oil and gas occurrence in the earth were very primitive. It was usually supposed that all oil seepages were connected with large cavities in the rocks, filled with oil and forming oil pools or underground rivers and streams. This, evidently, was reflected in the American term "pool."

From the beginning of drilling activities the oil men of Pennsylvania (which is considered the birth-place of the world's oil industry), both drillers and geologists, questioned the truth of the proposed idea that oil fills small openings in the rock-pores. It was largely believed that the discovery of oil was made by wells crossing fissures in a sedimentay series.

The prevailing opinions of the Russian petroleum workers of the same period were expressed by S. O. Gulishambarov thus: "Oil is found in hermetically

[1] Manuscript received, March 24, 1945.

[2] The Chair of Geology of Oil and Gas Fields, Moscow Petroleum Institute.

closed pores or caverns, linked together, and with interstices of 'floating' sand sediments" (1).

W. Romanovsky, mining engineer, after studying the known oil fields of Russia, in 1865 visited those of America, and he arrived at the conclusion, that the accumulation of oil is possible in solution-openings or cavities or locally within eroded rocks. As an exception, only, he permits the possibility of oil saturating porous rocks. In his opinion, oil fills fissures in oil-bearing strata. These fissures may connect or be isolated, and, in places, may reach the surface, or communicate with water-saturated beds (2).

The fact that oil and gas accumulations are commonly found on the crests of anticlines was first stated in a publication in 1842 by William Logan, director of the Canadian Geological Survey. He noted the relationship between oil and gas occurrences on anticlinal folds in the Gaspé oil field situated at the mouth of the St. Lawrence River. A similar occurrence of oil and gas on the crest of the anticline was, likewise, noted by Dr. Oldham in 1855, in a report concerning the Yenangyaung oil field of Burma (3). Later, a similar observation was made in Pennsylvania and reported by Henry D. Rogers to the Philosophical Society of Glasgow, in 1860. This was some months after the first commercial flow of oil from Colonel Drake's discovery well in Pennsylvania.

E. B. Andrews, in a paper describing the oil fields near Marietta in 1861 (4), likewise remarked on the accumulations of oil found near the crest of the Volcano Anticline in Ohio and West Virginia. According to his viewpoint oil accumulations on the crests of anticlines result from fissures, formed during folding processes. At that time the most popular opinion was that oil and gas occur in zones of fissures and not in porous beds.

OIL-BEARING ROCKS

The problem of permeable reservoir rocks where fluids—oil, gas, and water—are accumulated was first formulated by T. Sterry Hunt, Canadian geologist. In his description of oil accumulations in the Devonian limestone (Corniferous) of Western Ontario, Canada, he surmised that the concentration of oil within the arch of the anticlinal fold is achieved by water "propping it up." The separation, or segregation, of oil and water within a reservoir is in accordance with the differences in their specific gravities. Oil and gas seepages, according to Hunt, occur as a result of the penetration of the fluids through fissures in clays overlying the oil-bearing rocks (5). Hunt may be considered the author of the theory that fluids (water, oil, and gas) accumulate within porous beds and segregate in accordance with their specific gravities.

The conception of a porous rock and the conditions of oil and gas distribution therein were formulated by Mendeleev as follows.

> Let us suppose that a layer of sand is similar to a sponge suffused with oil; imagine the sponge surrounded on all sides by impermeable walls, that this closed space has higher and lower parts. Let us further suppose, that within this closed area there is a condensed gas . . . the gas must concentrate in the upper parts, and oil in the lower ones (6).

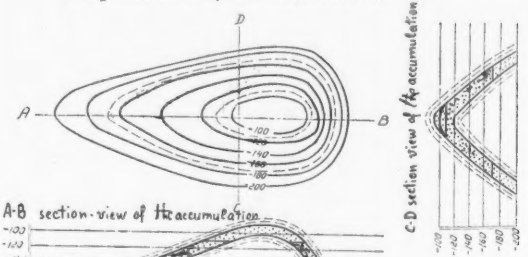
Types of oil and gas accumulations

Group I
Bedded accumulations
Subgroup A Bedded arched

Classification of accumulations
by J.O. Brod 1944

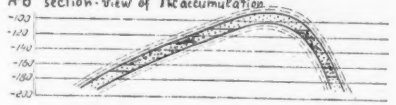
a) Unbroken

Horizontal view of the accumulation



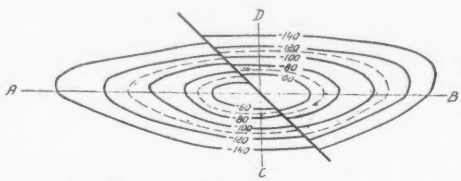
C-D section view of the accumulation

A-B section-view of the accumulation

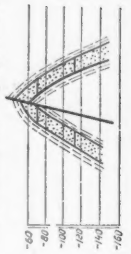


b) Slightly broken

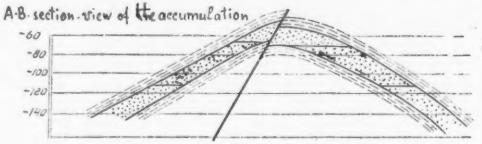
Horizontal view of the accumulation



C-D section view of the accumulation

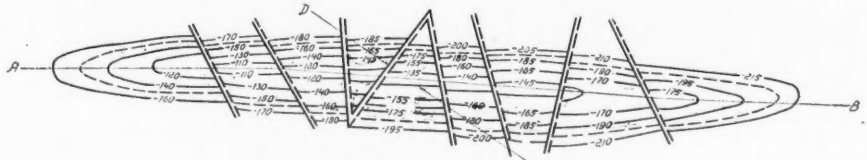


A-B section-view of the accumulation

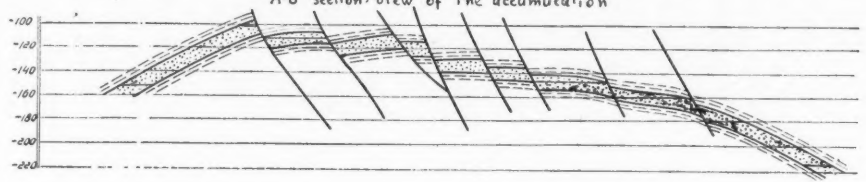


c) Broken by a system of faults into separate Blocks

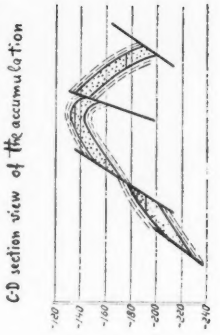
Horizontal view of the accumulation

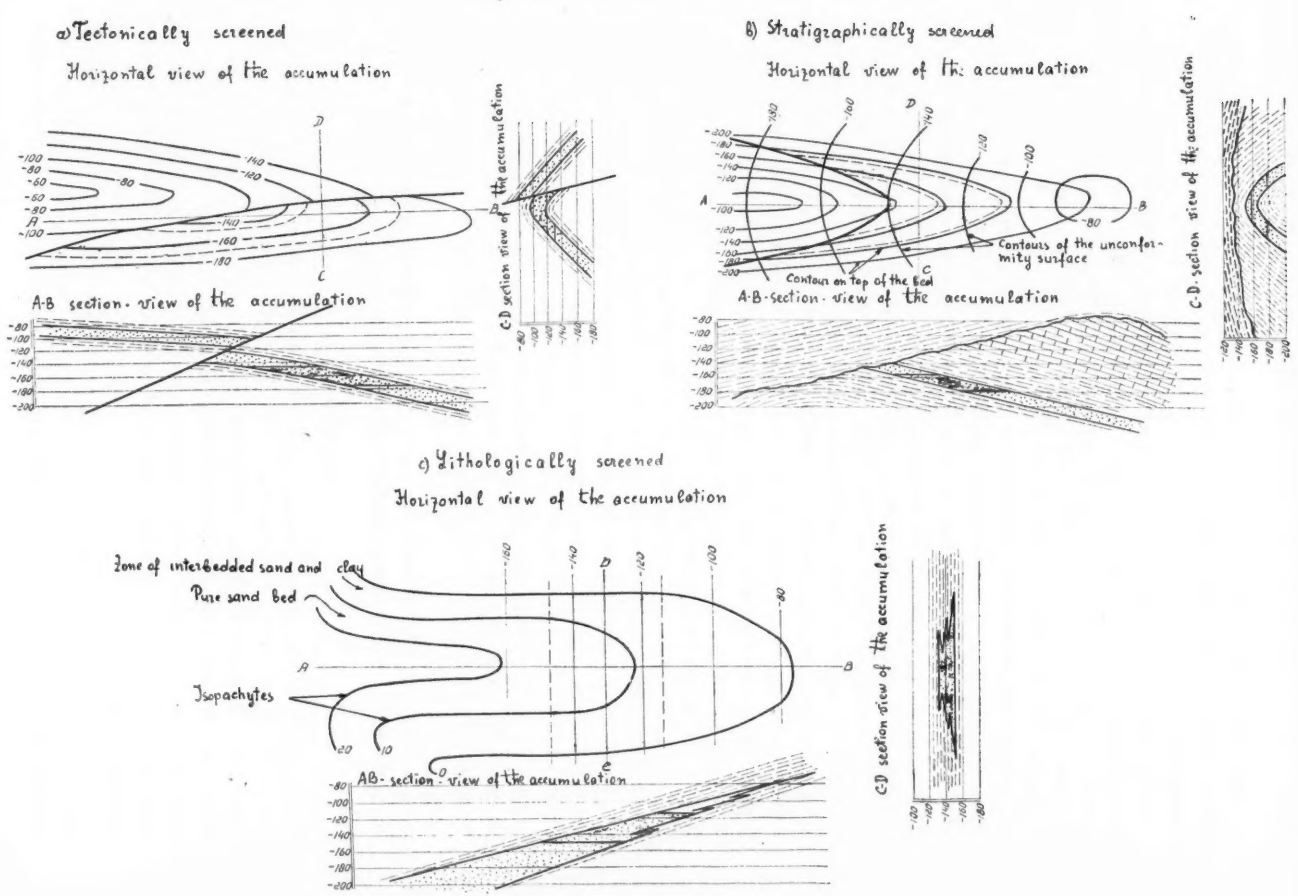


A-B section-view of the accumulation



C-D section view of the accumulation




Subgroup B. Bedded screened
a) Tectonically screened
Horizontal view of the accumulation
A-B section. view of the accumulation
C-D section view of the accumulation
b) Stratigraphically screened
Horizontal view of the accumulation
Contours of the unconformity surface
Contour on top of the bed
A-B-Section. view of the accumulation
C-D. section view of the accumulation
c) Lithologically screened
Horizontal view of the accumulation
Zone of interbedded sand and clay
Pure sand bed
Isopachytes
AB. section. view of the accumulation
C-D section view of the accumulation

PL. 1.—Writer's sketches to illustrate classification of oil and gas accumulations.
In each "horizontal view," broken contours mark contacts of water, oil, and gas on tops of structures.

The rocks which are capable of accumulating oil and gas, and afford oil recovery, have been termed in America "reservoir rocks." In Russia they are called "collectors."

The reservoir rock, shut in on all sides by rocks of poor permeability, serves as a receptacle for oil and gas. When comparing different types of oil and gas accumulations, American geologists usually term them "natural reservoirs," or, more often, "reservoirs." The term "natural reservoir" has been accepted, lately, in Russia ("prirodny reservuar").

A "natural reservoir" is specified by the writer as a natural receptacle for oil, gas, and water, within which the circulation of fluids may proceed. The form of the natural reservoir depends on the relationship between the reservoir rocks and the poorly permeable rocks surrounding them.

The oil-containing rock is called an "oil-bearing" rock ("nephtyanosnaya poroda" in Russian, "la roche de pétrole" in French, and "das Oelgestein" in German). A series of rocks, containing a number of reservoir rocks, saturated with oil or its products (asphalt, ozokerite, *et cetera*), is called an "oil-bearing formation" ("nephtyanosnaya svita" in Russian). Such rocks, containing gas accumulations are usually termed "gas-bearing formations" ("gasonosnaya svita" in Russian). Oil and gas-bearing formations are often called "producing formations" ("produktivnye svity" in Russian).

Natural reservoirs, which form a part of the producing series, are divided by poorly permeable rocks and may have the most varied forms.

A bedded natural reservoir represents a reservoir rock, limited, both at the top and at the bottom, by more or less parallel surfaces. Often, a series of fissured or cavernous dolomitized limestone, or a zone of increased porosity in limestone-dolomites, dense sandstones, or crystalline rocks, and, in some places, lens-shaped sand accumulations, serve as natural reservoirs. The term "oil-bearing," "gas-bearing," or "productive beds" should be used for bedded accumulations, only.

The term "producing zone" is used to define oil and gas accumulations within natural reservoirs of irregular shape in a geologic column.

SOURCE ROCKS

In many publications dealing with problems of origin of oil and gas accumulations, the term "oil-bearing" rock is contrasted with "source rock" ("nephtematerinskaya poroda" in Russian, "la roche mère de pétrole" in French, and "das Oelmuttergesteine," in German). The idea of a source rock was born from the conception that the accumulation of oil and gas is in connection with their flow from the underlying shale series, rich in organic content, into the reservoir rock.

As far back as 1872, J. S. Newberry, in his studies of the conditions of oil and gas occurrence, gave much attention to the problem of oil movement out of the argillaceous rocks, which he regarded as source rocks (7). A series of rocks

interbedded with rocks rich in organic content is generally called "source series" ("nephtematerinskie svity" in Russian, "source formation" in French, "die Oelmuttergeschichte" in German) (8). "Source series" and "source rocks" are, in the opinion of certain scientists, those, in which the formation of oil and gas took place, after which they accumulated in natural reservoirs.

An extreme adherent to the theory of the fundamental formation of oil, K. P. Kalicki, denies the existence of any other source rocks, and considers that oil originated in those rocks in which it is now found (9). The founders of different distillation theories, who based the origin of oil on the distillation of coal, peat, and bituminous shale, though often not mentioning the fact, actually considered them as source rocks. The study of bitumens, conducted in the last 10 years, has shown that all analyzed oils and bitumens contain porphyrin combinations that are genetically associated with the tinctorial matter of green plants and animal blood. These combinations, being of a complicated and fragile structure, can not bear oxidation and vanish upon an increase of temperature above 200–250°C. (10). The presence of porphyrins in oil and other bitumens proves that high temperature distillation was impossible during the formation of these bitumens. Therefore, rocks containing bituminous matter, that bear evidence of high-temperature distillation, can not be considered source rocks. The problem of source rocks, to which attention had been drawn from the very beginning of the development of the oil industry by Newberry and other scientists, even to this day can not be considered as solved. The main elements of the solution of this problem are contained in the definitions of the following:

1. The organic source material for the formation of oil, gas and other bitumens;

2. The conditions of accumulation and the environments in which it takes place, which determine the trends of initial change, both of the organic matter and the sediment as a whole (the character of the facies and the diagenetic conditions);

3. The sum total of the conditions required for the further transformation of the organic matter into gaseous, liquid, and solid bitumens or bituminous rocks;

4. The means and causes of the primary movement of gaseous and liquid bitumens from the source rock into the reservoir rocks, in which oil and gas accumulations are formed.

The writings of many scientists have been devoted to the solution of these problems and others, closely related. Following the individual declarations and publications of this first period, other works appeared that were more or less devoted to the whole cycle of these problems, such as the works of S. Engler, H. Hoefer, F. Potonie, David White, Krejci-Graf, A. D. Archangelsky, G. L. Stadnikov, P. D. Trask, V. B. Porfiriev, and others.

Porfiriev, in his work, published in 1941, attempted a close analysis of the total data gathered by chemical investigations and geological observations,

partly connected with the problems of the formation of all types of bitumens and bituminous rocks (11). Tables are added that contemplate collaterally the geological and chemical conditions of the accumulation and transformation of the sediments. Notwithstanding the fact that Porfiriev subjects to a stiff criticism all the "source-rock series" theories and insists on the exclusion of the very expression from the theory and practice of geological prospecting, the tables proposed by him, not only do not dispose of the idea, but emphasize even more the conception of source rocks. The summary of the chief chemical conditions and geological surroundings that determine the possibility of oil formation, given in Porfiriev's tables, include the distinguishing features typical of source rocks.

If by fossil facies may be understood sediments covering an area of comparatively similar formation and primary transformation conditions ,the aforementioned tables can be considered as giving a definition of a source-rock facies, according to Porfiriev. Source-rock facies form part of a sedimentation series, which consists, besides, of non-source rocks. Such source-rock series, if they consist of a number of source-rock facies, may be called "source-rock formations." The conception of "source rocks" is genetically related to that of "source-rock facies." "Source-rock series" correspond, genetically, with "source-rock formations." The latter reflects the sedimentation cycles at a certain stage of geological history.

If a coal series may at the same time be considered a source series for coal it is not so in respect to the definition of oil and gas source formations. Coal, bituminous shale, and other caustobioliths, having originated in a solid phase remain up to the present moment in the same deposits in which they were formed. All matter, existing or having existed in the earth in a gaseous or liquid phase, undergoes more or less movement. The magnitude of removal depends on a number of geological and physico-chemical factors which may at times be significant. This explains the need of a clear distinction between the terms "oil-bearing" and "source" series.

By an "oil-bearing series" is understood a series which includes rocks with a present oil content. This series, however, may not necessarily be a source series. The recognition of a source series must be based on analyses of geological conditions of formation and of fundamental changes in the sediments. Every definition of a series, facies, and formation as a source is conventional. First of all, it is connected with the difficulties of re-establishing the geochemical surroundings of fossil basins and, even more so, their separate parts. Besides, the process of transformation of the organic matter into liquid and gaseous bitumens, can not be considered fully worked out and proved by exhaustive evidence.

The terms "source series," "source facies," and "source formations" are useful, therefore, only when applied to paleogeographic reconstructions, accompanied by an analysis of geochemical conditions of formation and of primary transformation of sediments.

II. ACCUMULATIONS OF OIL AND GAS

DEVELOPMENT OF IDEAS

The first 70 years of the history of the oil and gas industry were characterized mainly by the development of the "structural theory" of the formation of oil and gas pools. The chief attention of most scientists was directed toward the study of the relationship between the accumulations of these natural resources and the structural form of the series of rock composing the pools.

The first scientists who noted the connection between oil and gas accumulations and anticlinal folds have already been mentioned.

During the period of 1910–1930 a number of classifications appeared dealing with different structural forms and their association with oil and gas areas. The classification proposed by F. G. Clapp in 1910–1911 and completed in 1929–1930, may be considered a summary of all the former works in this field (12, 13). Clapp's classification, slightly modified, was accepted by I. M. Gubkin, member of the Academy of Science of the U. S. S. R., in his *Science of Petroleum* (14).

Soon after the appearance of the "anticlinal" or the so-called "structural theory" of oil and gas fields, several works were published that rejected or considerably discredited the role of the structural factor of oil and gas accumulations. Thus, many data were gathered by J. P. Lesley and his associates in the process of their investigations begun in 1874 (15). The conclusions drawn by M. J. Munn (16), Chester W. Washburne (17), Alex W. McCoy (18), K. P. Kalicki (19), John L. Rich (20), and many others, proved that the accumulation of oil and gas depends mainly on the character of the reservoir (reservoir rock) in which the concentration and distribution of the saturating fluids (oil, gas, and water) take place.

A classification dealing with the types of natural reservoirs containing oil and gas, and not based on structural forms solely, was proposed in 1934 by W. B. Wilson (21). Wilson subdivided oil and gas reservoirs, first of all, into "closed" and "open" reservoirs. The latter, not being of commercial value (because of the oil having had a means of escape), were not included in his study.

Wilson subdivided closed reservoirs into four groups:

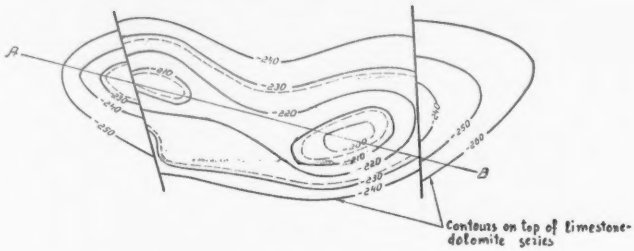
1. Reservoirs closed by a local folding of the strata;
2. Reservoirs closed because of a varying porosity of the rock;
3. Reservoirs closed by a combination of folding and varying porosity;
4. Reservoirs closed by a combination of faulting and varying porosity.

The period following the appearance of Wilson's classification is characterized in the United States of America by a detailed study of natural reservoirs in which the accumulation of oil and gas is associated, mainly, with the lithological factor and stratigraphical relationships between the reservoir and the overlying and underlying rocks. Reservoirs of this type are called by American geologists "stratigraphic traps" (22).

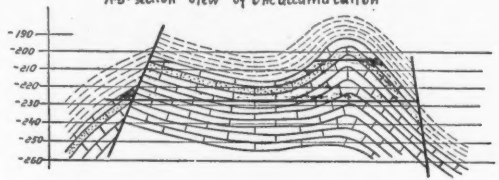
Group II Massif accumulations

Subgroup A. Tectonic (structural) projection massif accumulations

Horizontal view of the accumulation

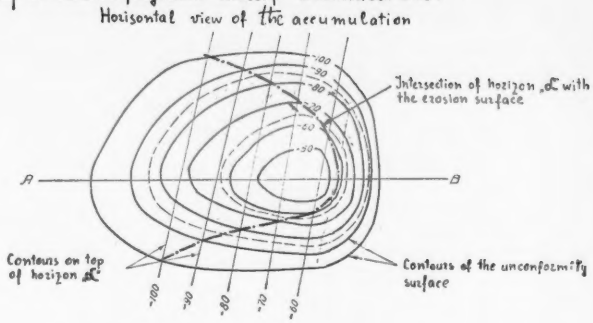


A-B section view of the accumulation

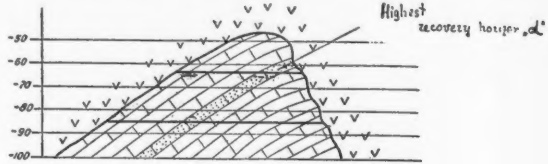


Subgroup B. Erosion projection massif accumulations.

Horizontal view of the accumulation

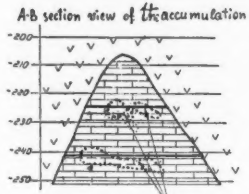

Intersection of horizon „d" with the erosion surface
A
B
Contours on top of horizon „d"
Contours of the unconformity surface

A-B section view of the accumulation

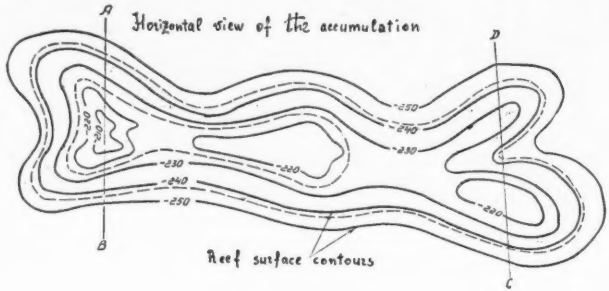


Subgroup C. Massif accumulations in reef projections

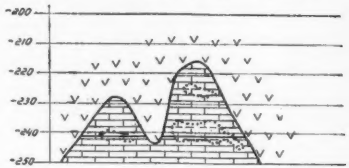
A-B section view of the accumulation

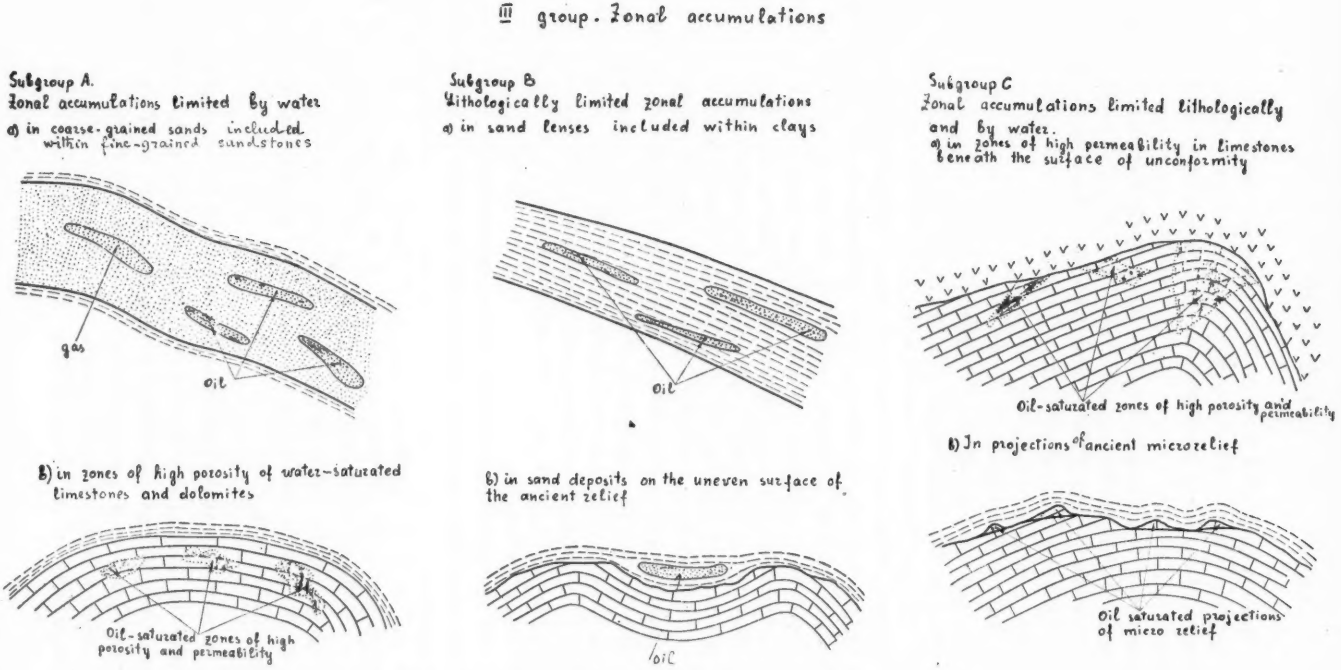


Horizontal view of the accumulation



C-D section view of the accumulation.




III group. Zonal accumulations
Subgroup A.
Zonal accumulations limited by water
a) in coarse-grained sands included within fine-grained sandstones
gas
oil
Subgroup B
Lithologically limited zonal accumulations
a) in sand lenses included within clays
oil
Subgroup C
Zonal accumulations limited lithologically and by water.
a) in zones of high permeability in limestones beneath the surface of unconformity
Oil-saturated zones of high porosity and permeability
b) In projections of ancient microrelief
B) in zones of high porosity of water-saturated limestones and dolomites
Oil-saturated zones of high porosity and permeability
b) in sand deposits on the uneven surface of the ancient relief
oil
Oil saturated projections of micro relief

PL. 2.—Writer's sketches to illustrate classification of oil and gas accumulations.

Numerous works by A. I. Levorsen and other scientists provided many data on the conditions of the occurrence of oil and gas accumulations within natural reservoirs, which in Russia are known as "stratigraphic accumulations" (Mirtchink, 23).

In accordance with these studies, classifications dealing with "stratigraphical traps" appeared. Among these may be noted J. A. Kornfeld's classification (24), based on a detailed study of the oil and gas fields of the Central Kansas uplift. Kornfeld divided all "stratigraphic traps" into four groups:

1. Wedge reservoirs;
2. Unconformable sands;
3. Reservoirs due to changes in porosity;
4. Reservoirs due to buried topography.

As the principal feature of classification, Kornfeld has chosen the conditions of formation of a reservoir rock serving for the accumulation of oil and gas.

The "structural" classifications (Clapp and others) were always a basis for differentiating types of structures, with which are usually connected a number of oil and gas accumulations known in the different formations of a single field.

The classification of "natural reservoirs" (Wilson, Kornfeld, and others), on the other hand, characterize types of elementary oil and gas concentrations within each separate reservoir, that is, types of accumulations.

Recently, the term "stratigraphic traps" has become widely known and is used by many geologists, not only to characterize elementary oil and gas accumulations, but also combinations of several accumulations, connected with large wedged zones or with unconformities. Thus, the term "stratigraphic type oil field" has arisen. Such is the name of the symposium published in 1941 under the editorship of Levorsen (25). The same idea was reflected in Levorsen's publications in 1943 (26).

The contrasting of structural and stratigraphic factors, controlling the formation of accumulations, has given rise to a similar subdivision of large oil zones into two groups.

The studies of W. B. Heroy (27), K. C. Heald (28), H. R. Lovely (29), C. W. Sanders (30), M. W. Abramovitch (31), I. W. Visotsky (32), M. A. Jdanov, (33), G. A. Helkvist (34), the present writer (35, 36, 37), and others, devoted to the classification of oil and gas accumulations, proved that the formation of most known local traps is caused by a combination of structural-stratigraphic, or structural-lithologic, factors.

CHIEF PRINCIPLES OF CLASSIFICATION OF OIL AND GAS ACCUMULATIONS

It may be maintained that the existing division of accumulations into "structural traps" and "stratigraphic traps" deprives us of the possibility of differentiating all types of accumulations on the ground of a study of the similarity and differences between their groups, sub-groups, and types. Such a division of accumulations has its historical basis. At first, there was emphasis on struc-

tural factors in the accumulation of oil. Later, they were opposed by stratigraphic factors.

It is not accidental that 8 years after the publication of his classification, Wilson, in 1942, once again stated, that "a perfectly satisfactory classification of oil and gas reservoirs has not yet appeared" (38). This is connected mainly with the fact that in recognizing certain types according to the existing classification, individual oil and gas accumulations are often compared with groups or even with large territorial zones of numerous accumulations. In working out a classification it is necessary to proceed from an analysis of the known regularities in the distribution of oil and gas accumulations. First, it is necessary to differentiate types of great geological zones, types of individual structures found inside the zones, and, lastly, types of individual accumulations in separate natural reservoirs.

As a result of investigations, geologists have recognized in nearly all oil and gas provinces several zones within which the distribution of oil and gas accumulations, as well as their formation, is controlled by uniform or genetically similar geological conditions. These conditions represent a combination of stratigraphic and structural factors which together cause the formation of the whole group. Generally, either structural factors (large uplifts, complex anticlines, anticlinoriums, regional faults, *et cetera*) or stratigraphic factors (regional unconformities, wedging-out zones of sedimentatary series, *et cetera*) dominate.

As a result, it is possible, almost without exception, to differentiate a local structure deformation, which controls the formation of each group of oil and gas accumulations saturating rocks of different lithologic composition, from different stratigraphic horizons within an area. In each case of an individual oil and gas accumulation, contoured by wells, it is necessary to determine the cause for the concentration of the fluids in this part of the natural reservoir, that is, the cause of the occurrence of a trap in which the accumulation was formed.

The lack of exactness in the delimitation of these phenomena is comparable with the indefiniteness in the usage of the basic terminology of oil and natural gas geology.

DEFINITION OF TERMS: ACCUMULATION, POOL, OIL AND GAS FIELDS

The problem of the delimitation of the conceptions of an individual accumulation and a combination of accumulations occupying the same structure has long been unsolved. Until lately there did not exist a satisfactory definition of these terms, either among Russian or American geologists (M. W. Abramovitch, 31, p. 324).

C. W. Sanders, in one of his papers published in 1943, noted that it has for long been necessary to differentiate the treatment of the classification of individual oil accumulations on one structure (30).

The classifications of oil accumulations should be based on principles different from those used in classifying oil and gas pools. In the classifications of ac-

cumulations the chief role is afforded the conditions under which oil and gas concentrate within the natural reservoir, serving as a receptacle; whereas in the classifications of oil and gas pools it is necessary to analyze the cause of the common occurrence of a number of accumulations upon a structure.

Every individual accumulation of oil and gas proceeds within a natural reservoir. The form of the accumulation corresponds with the shape of the reservoir only where the reservoir rock, saturated with gaseous and liquid hydrocarbons, is limited on all sides by rocks of low permeability. More commonly, the reservoir is filled with water and the accumulation of oil and gas occupies only that small part of the reservoir which serves as a trap. In Russian the term trap is translated "lovushka."

The formation of traps in a natural reservoir, covering a large area, is related to the limitation of an oil (or gas) accumulation by water.

This can be in consequence of:

1. A favorable structural deformation (brachy-anticline, or screening faults);
2. A change in the lithological composition of the reservoir rock;
3. An overlapping of the reservoir rock by poorly permeable rocks (stratigraphic screening);
4. Various combinations of the foregoing factors.

In a particular case where the reservoir rock is limited on all sides by rocks of low permeability, water does not influence the accumulation of oil and gas, and in places, may be altogether absent. A trap causes the formation of an oil or gas accumulation within a natural reservoir.

The term "accumulation" is defined by the writer as "an oil or gas accumulation limited on all sides within a natural reservoir." Ordinarily, the accumulation is limited partly by poorly permeable rocks and inside the reservoir by water. In particular cases, where water is absent from the natural reservoir, the accumulation may be fully limited on all sides by poorly permeable rocks. In certain instances, oil and gas accumulations may be surrounded on all sides by water. This occurs when oil and gas are contained in limited zones of increased porosity and permeability within water-filled natural reservoirs. According to the writer's views, therefore, an accumulation is an individual oil or gas accumulation.

In the publications on the geology of oil and natural gas the terms "oil and gas accumulation" and "oil and gas deposit" are commonly used as synonyms. However, since oil and gas are fluids the term "accumulation" is more correct.

Oil and gas accumulations are called in Russian "zalezjinephti," in French "l'accumulation de pétrole," and in German "das Erdoellager" ("das Erdgaslager").

In the Russian literature the term "mestorozjdenia" is widely employed to determine oil and gas areas and, sometimes, oil and gas seepages. In English, French, and German, a term equivalent to "mestorozjdenia" does not exist. Instead, different terms are used corresponding with locality, place of deposit, *et*

cetera. The literal translation of the term "mestorozjdenia" into English is "birthplace," "origin-place," into French "la place de naissance" or "la place d'origine." However, these are not used in the literature. The corresponding German term "das Geburtsort" has a limited use in the mining industry.

The Russian term "mestorozjdenia" originated in the mining industry in application to different mineral resources and on the grounds that the place of accumulation of the mineral resource is also the place of its origin. At the first stage of study every oil and natural gas seepage was considered at its place of origin. Later, when it became known that most of the oil and natural gas seepages are related to accumulations in the earth's depths, the term "mestorozjdenia" was applied to such accumulations, or their combinations that were thought to have originated locally (without migration). Still later, the term was expanded to include all types of accumulations of oil and gas (Gubkin, 14, p. 156; Hoefer, 39, pp. 129–30; Abramovitch, 31, p. 324).

The American term "pool" usually corresponds with the Russian term "mestorozjdenia."

Ver Weibe suggests that "the word *pool* be restricted to the smallest unit into which a petroliferous province could be divided and should refer to a number of wells forming a nearly uninterrupted group" (40).

The term "mestorozjdenia" ("pool") is extremely indefinite and in publications on oil and gas has different meaning.

The writer proposes to recognize under the term "mestorozjdenia" ("pool") all those oil and gas accumulations which are bounded by a common area and the formation of which is controlled by a uniform structural element.

In the particular case where the area includes a single accumulation the terms "pool" and "accumulations" become synonymous.

The Russian term "neftenosnava ploshchad" corresponds with the American term "oil field," the English "oil area" and French "champ de pétrole." This term is mainly territorial (areal). It may be applied to any area with known oil and gas seepages or accumulations that are associated with one or a few adjacent pools. In certain cases an oil or gas field may be composed of a combination of pools associated together by common formation features, that is, by a uniform combination of structural and stratigraphical factors which cause the accumulation of oil and gas. To such areas may be applied the term, "oil- and gas-bearing zone" ("neftegasonosnaya zona"). A "neftegasonosnaya zona" is considered a part of an oil- and gas-bearing province ("neftegasonosnaya provintsia"). The last two terms are mentioned to show the relationship between the mentioned conceptions of accumulation and pool with larger genetic subdivisions.

The problem of the earliest and the present conceptions of the terms oil "zone" and "province" surpasses the limits of this theme and therefore must be examined in connection with the main type of oil or gas provinces.

In the following paragraphs the basic types of oil and gas accumulations are discussed according to the proposed terminology and the selected names are shown to be appropriate.

III. BASIC TYPES OF OIL AND GAS ACCUMULATIONS

PRINCIPLES OF CLASSIFICATION OF ACCUMULATIONS

In the determination of the types of oil and gas accumulations three factors are to be taken into consideration:

1. The form of the fluid-containing reservoir;
2. The pool structure;
3. The relationship and interaction of water, oil, and gas within a reservoir.

The classification of oil and gas accumulations proposed by the writer in 1937 was based on the type of reservoir ("bedded" and "irregular"); subgroups and types of accumulations were differentiated in accordance with the deformation of the strata, including the reservoir (35, 36). Upon examination of the data concerning the conditions of oil and gas accumulation in various platforms, foothills, and intermontane regions, the writer found it necessary to recognize three groups of accumulations, as given in the following paragraphs.

Group 1. Bedded accumulations.—Bedded accumulations are those in bedded reservoir rocks, which are overlain and underlain by strata of low permeability. Such accumulations are limited within the bed by edge water. For example, in the particular case where the accumulation is small and the bed thick, the accumulation may be limited by water.

Group 2. Massive accumulations.—Massive accumulations are those formed in elevated projections of thick series covered by rocks of low permeability. Inside such a massif the fluids are distributed in accordance with their specific gravities, independent of the mode of occurrence of the rocks, and the oil and gas accumulation is limited by bottom water. The surfaces separating the fluids cut or intersect the body of the massif which represents a single reservoir from the standpoint of the formation of the accumulation.

Group 3. Irregular accumulations.—Irregular accumulations were termed by G. A. Helkvist "zonal accumulations" (34). This term was likewise accepted by the writer. The reservoirs of such accumulations are represented by sand bodies of irregular shape restricted to rocks of low permeability, or zones of sufficient porosity and permeability within carbonate or crystalline rocks. In most cases such accumulations are lithologically limited on all sides. Some of these reservoirs contain oil, gas, and water which are distributed according to their specific gravities. Water within zonal accumulations plays only a passive role. In bedded and massive accumulations, however, water is the chief factor in accumulation.[3]

BEDDED ACCUMULATIONS

The main factor in the formation of bedded accumulations is local deformation of strata (folds or faults). Bedded accumulations are divided into two subgroups:

[3] Zonal accumulations, according to Helkvist, include accumulations in wedging beds, as defined by the present writer in his classification, published in 1937 (35,36). From the aforementioned principles and the stated definitions it follows that accumulations in wedging beds are at present included in the group of bedded accumulations.

Subgroup A. Arched accumulations;

Subgroup B. Screened accumulations.

The further subdivision of arched accumulations is based on the degree and type of faulting of the arch. Three types of screened accumulations are recognized in beds which are in contact updip with poorly permeable rocks:

(a) Tectonically screened by faults,

(b) Stratigraphically screened by an unconformity,

(c) Lithologically screened by the wedging-out of the reservoir rock.

Tectonically and stratigraphically screened accumulations, as well as those in wedging beds, are generally formed on monoclines or on the flanks or closures of anticlines. Such accumulations may be formed only on condition that the oil and gas are propped up by water to the surface limiting the reservoir rock.

MASSIVE ACCUMULATIONS

In the formation of a massive accumulation the principal factor is the form of the surface that limits, at the top, the rock series serving as a reservoir for oil and gas. An accumulation may be formed where the water, "propping up" the oil and gas, confines them within the upper projections.

The structural form of the rock series, containing the oil- and gas-saturated reservoir, is of importance in the formation of such massive accumulations only as are included in projections of tectonic origin.

Massive accumulations may be divided into three subgroups according to the origin and the conditions of formation of the reservoir-rock projections:

A. Tectonic projection,

B. Erosion projection,

C. Reef projection.

The types of accumulation of each subgroup are determined according to the texture and mode of occurrence of the projected rocks. The chief problem in classifying massive accumulations is in the characteristic of the distribution and location of zones of high permeability which stipulate uneven oil and gas recovery within a unit massive accumulation. This is connected with the fact that the massif, representing a unit reservoir, becomes divided during the process of exploitation into several separate zones differing in recovery properties. Thus, wells exploiting oil from adjacent porous zones, separated by sections of low permeability within a massive accumulation, exercise hardly any influence upon each other. During the exploitation of gas caps or massive gas accumulations, because of the much greater mobility of gas, the whole massif will behave as a single accumulation.

ZONAL ACCUMULATIONS

In the formation of zonal accumulations the structure of the rock series containing the oil- and gas-saturated reservoir is still less important than in the case of massive accumulations. In the recognition of zonal accumulations the form

and texture of the oil- and gas-containing reservoir, and the relationship between the reservoir and the poorly permeable rocks surrounding it, are of principal importance.

Zonal accumulations may be divided into three subgroups according to the formation and occurrence of oil and gas.

A. Water-limited zonal accumulations. These accumulations are included within zones of high permeability in fine-grained water-saturated rocks.

B. Lithologically limited zonal accumulations in irregularly shaped reservoirs within poorly permeable rocks.[4]

C. Lithologically limited and water-limited zonal accumulations.

Types of accumulations may be differentiated within each subgroup, according to the character of the reservoir rock (carbonate or sandy) and its origin. Examples are: classic accumulations upon an irregular surface of ancient relief; coarse-grained lenses within fine-grained sands or shales; erosion surfaces and projections of ancient micro-relief; fissured and cavernous zones in carbonate and crystalline rocks.

The proposed terms and their meanings are presented in connection with the writer's classification of oil and gas accumulation and pools.

A number of the aforementioned problems are stated for discussion. Thus, a precise distinction of the accepted terms and basic conception in oil and gas geology may be achieved.

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PRELIMINARY OBSERVATIONS ON GEOLOGICAL USE OF AERIAL PHOTOGRAPHS[1]

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ABSTRACT

This paper presents the results of the writer's experience with the geological use of aerial photographs. The writer is very optimistic about the future of aerial photography for geological discovery, not only in the wilderness but in certain regions with a long history of exploration by other methods. Yet in the field of topographic mapping it is apparent that too much has been expected of the stereoscopic study of photos—a mistake which is not confined to geologists. Stereoscopic mapping does not yield results of great accuracy unless pains are taken to establish a sufficient number of benchmarks by ground surveying.

Some of the common faults in stereoscopic vision are discussed, as are some of the causes of distortion in the stereoscopic model.

Photo-indexes in terrane of low relief, such as the low-strata-bench-lands and true plains, if properly prepared, are valuable "picture maps," instead of being, as they originally were intended to be, merely a guide to the location of the contact prints from the flight negatives.

In regions of low relief mosaics have a cost out of proportion to their geological value; a good photo-index sheet is to be preferred for geological study. In regions of high relief, however, the mosaic is thus far the only suitable device for securing a continuous picture map, and as such is very valuable. In studying terrane of either low or high relief, the geologist will always need stereoscopic contact prints for the most satisfactory work.

It is premature to make definite statements about the exact degree of usefulness of aerial photographs in geological exploration, since photos have seldom been made to the specifications of the geologists who study them. It happens all too frequently in photos of the low-strata-bench -lands that the bedding is not visible even when magnification is used.

Nevertheless, if aerial photographs are used chiefly for discovery the writer feels that the expense will prove to be a negligible quantity in comparison with the high returns.

INTRODUCTION

The use of aerial photographs by geologists is a complicated technique which touches several fields of geologic thought and practice. It may be compared with the use of other instruments such as the petrographic microscope, which also touches the broad field of geology at many places. If the following comments seem too brief and too abrupt it is because the subject is broad and space is limited. Because of this limitation, some elementary concepts and photo-procedures, discussed rather fully elsewhere, are omitted. The paper aims to deal mainly with the geological interpretation of contact prints from the flight negatives as well as with the interpretation of photo-indexes and mosaics. Accordingly, considerable space must first be given to stereoscopic vision with contact prints.

CONTACT PRINTS FROM FLIGHT NEGATIVES

STEREOSCOPIC VISION WITH OVERLAPPING CONTACT PRINTS

The geologist engaged in the study of aerial photographs will always want to use stereoscopic vision with contact prints. Stereoscopic study gives what may be called "the stereoscopic image or model," or, more briefly, "the stereo-model,"

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of a small part of the earth's surface. The stereo-model is of greatest value in helping the geologist to evaluate topographic form, to estimate the strike and dip of bedding, and to recognize faults. While there is no doubt that the stereoscopic use of aerial photographs has its limitations, in most cases it will increase the geologist's usefulness and accuracy many times beyond what they would be, were he to use aerial contact prints singly, without the stereo-effect.

Nevertheless, the value of the stereoscopic model in purely topographic mapping has probably been overestimated. For example, it is impossible by a strictly stereoscopic use of available photos to recognize a level surface within $\frac{1}{2}$ to 1 per cent of slope without the use of bench-marks. These percentages are the writer's estimates—they depend on the quality of the lens, the amount of overlap, and the relief of the ground surface, not to mention the tilt of the camera axis and other factors. With suitable ground control much greater accuracy can be secured. An experienced geologist or topographic engineer can estimate fairly accurately the direction, but not necessarily the amount, of dip of visible bedding, without using the stereo-model except as an aid in tracing the continuity of beds.

In aerial photos the image is focused upon a plane surface, the negative. Two of these plane-surface images are then focused upon curved surfaces, the retina, and are fused by the brain into one stereo-model. It would be surprising indeed if this last perception were a true scale model of the topography shown.

Many experienced observers can fuse the images of a stereo-pair of photos differing from each other in scale by 10 per cent or even more, but inexperienced observers can not easily fuse such unequal images.

COMMON FAULTS OF STEREOSCOPIC MODEL OF TOPOGRAPHY

All students of aerial photos have noticed the concave, *bowl-shaped* aspect of the stereo-model produced by nearly all the available photographs. Photo-engineers claim this is the result of inadequate lenses. Though sufficiently good lenses may have been designed, they are not yet in common use. For geological purposes aerial photos should not utilize the entire field of the lens unless it is understood that a considerable part of each photograph must be cut off. By proper cutting, a less distorted central part of each photograph may be made accessible for close study with a magnifying stereoscope. But unless the overlap has been planned to make this possible, certain parts of the photographed area may be lacking for closely detailed stereoscopic study. The best geological interpretation requires that only the central part of photographs be used, and that the lens have relatively long focal length—10 or 12 inches or even more if cost will permit.

Stereoscopic vision depends to a certain extent on the recognition or perception of detail. Stereo-pairs of aerial photos have occasionally been made of heavily wooded areas with all relationships normal except that one photo was made in the forenoon and the other in the afternoon; this caused the tree shadows in the stereo-pair to fall in two directions, nearly perpendicular to each other. In such

a stereo-pair, it may be impossible to resolve the topography into a stereoscopic model, even though the per cent of overlap may be normal, tilt and "crab" may be absent, and even though the scale of the two photos may be the same. Unless the hill-form is large and striking, it may be obscured by the divergent tree shadows.

DISTORTION OF PERSPECTIVE

The correct relative position of a stereo-pair of aerial photographs to give the best possible stereoscopic model is a problem worthy of discussion. It has been

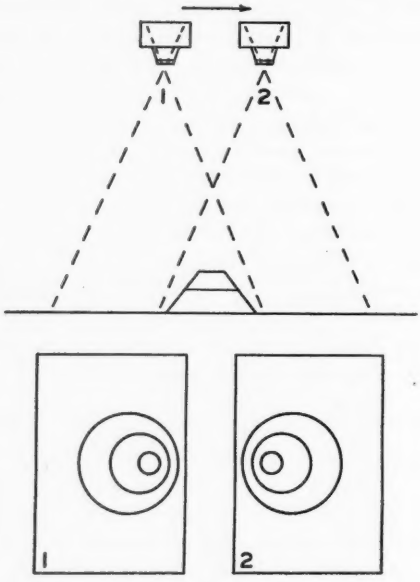

FIGURE 1

stated in numerous textbooks and articles in photogrammetry, that the only "correct" orientation of contact prints for stereo-vision is the "line-of-centers" orientation. In this method, the observer places a stereo-pair of overlapping photos in such a position that the ground-images at center-points, together with the observer's eyes, fall in a single plane. In other words (if perfectly regular conditions be assumed, such as straight flying, freedom from tilt of camera axis, *et cetera*), the "line of flight" *on the photos* and the eyes of the observer should fall in the same plane. This is general practice and is, indeed, the only satisfactory method to use in geologic interpretation or other types of map work with stereoscopic pairs of aerial photos.

However, it should be pointed out that so far as the stereoscopic image or model alone is concerned, the "line of centers" or (under ideal conditions) the "line of flight" may be disregarded. Figures 1 and 2 illustrate the "distortion of the perspective" which is under discussion. Figure 1 shows the geometric relationships of the perspective of a symmetrical flat-topped conical hill marked by contours at the top, middle, and base. If the hill lies in the marginal area of two consecutive vertical photos, its photographic images on the contact prints will be asymmetrical because of the perspective or obliquity at the margin.

Figure 2 illustrates the sequence of changes in stereoscopic and non-stereoscopic, though binocular, vision of this ideal stereo-pair, as each print of the pair is rotated toward the right under binocular vision with suitable stereoscopic instruments. The following table will clarify the diagrams.

a. Relative position of the ideal stereo-pair for *stereoscopic vision with normal relief*. This is the correct position for stereoscopic work, but not the only position.
b. The stereoscopic image begins to disappear for most observers between 30° and 60° of rotation toward the right or left.
c. With 90° rotation the stereoscopic image can not be seen but a "pseudo-stereoscopic" image is clear and distinct. In other words a clear picture is visible but there is no stereoscopic relief. This is one of two positions of "*extinction*" for the stereoscopic image. See diagram "g."
d. With further rotation to $135° \pm 15°$ from the starting position, a stereoscopic model begins to appear in reverse relief. This is one of the limiting positions for *stereoscopic vision with reversed relief*. The other limit is the position $225° \pm 15°$. See diagram "f."
e. The rotation is 180°. This is the *optimum position for stereoscopic vision with reversed relief*. It is the direct opposite, both in orientation and perception, of the correct position for stereoscopic vision with normal relief shown in diagram "a." Reverse relief is as easily seen by an experienced observer as normal relief; it is, in fact, on rare occasions useful to the geologist.
f. With further rotation to $225° \pm 15°$ from the starting position, *stereoscopic vision with reversed relief* begins to disappear. This is one of the limiting positions for stereo-vision with reversed relief. The other limit is the position $135° \pm 15°$. See diagram "d."
g. The rotation is 270°. This is one of the two positions of "*extinction*" for the stereoscopic image and for the appearance of the pseudo-stereoscopic image. See diagram "c."
h. The stereoscopic image with normal relief begins to reappear for most observers between 30° and 60° to the left of the starting position. This is $315° \pm 15°$ of rotation toward the right and $45° \pm 15°$ of rotation toward the left of the starting point.
i. The starting position. See diagram "a."

To repeat for emphasis: "Distorting the perspective" of a stereo-pair, by rotating both photos far toward the left and toward the right, does not noticeably distort the stereoscopic model. Nevertheless, for reasons of uniform and rapid handling of photos as well as easy perception of the stereoscopic image, the customary orientation of aerial photos is best.

CAUSES OF DISTORTION OF STEREOSCOPIC MODEL

Some of the chief factors which cause noticeable distortion of the stereoscopic model are the following.

a. Bending of either contact print while under stereoscopic observation.
b. Moving the line of sight away from a position perpendicular to the prints. Such changing of the line of sight results in "weaving topography." A horizontal surface will appear to tip one way or another as one moves his head in translation in any direction.
c. Imperfections in lenses which cause distortion of the photo-image.
d. Tilt of the axis of the camera away from the vertical position, in one print of a stereo-pair, may possibly distort the stereoscopic image if the angle of tilt is large. However, if the tilt is only a few degrees and if ground control is lacking, even an experienced observer will not see any noteworthy distortion.

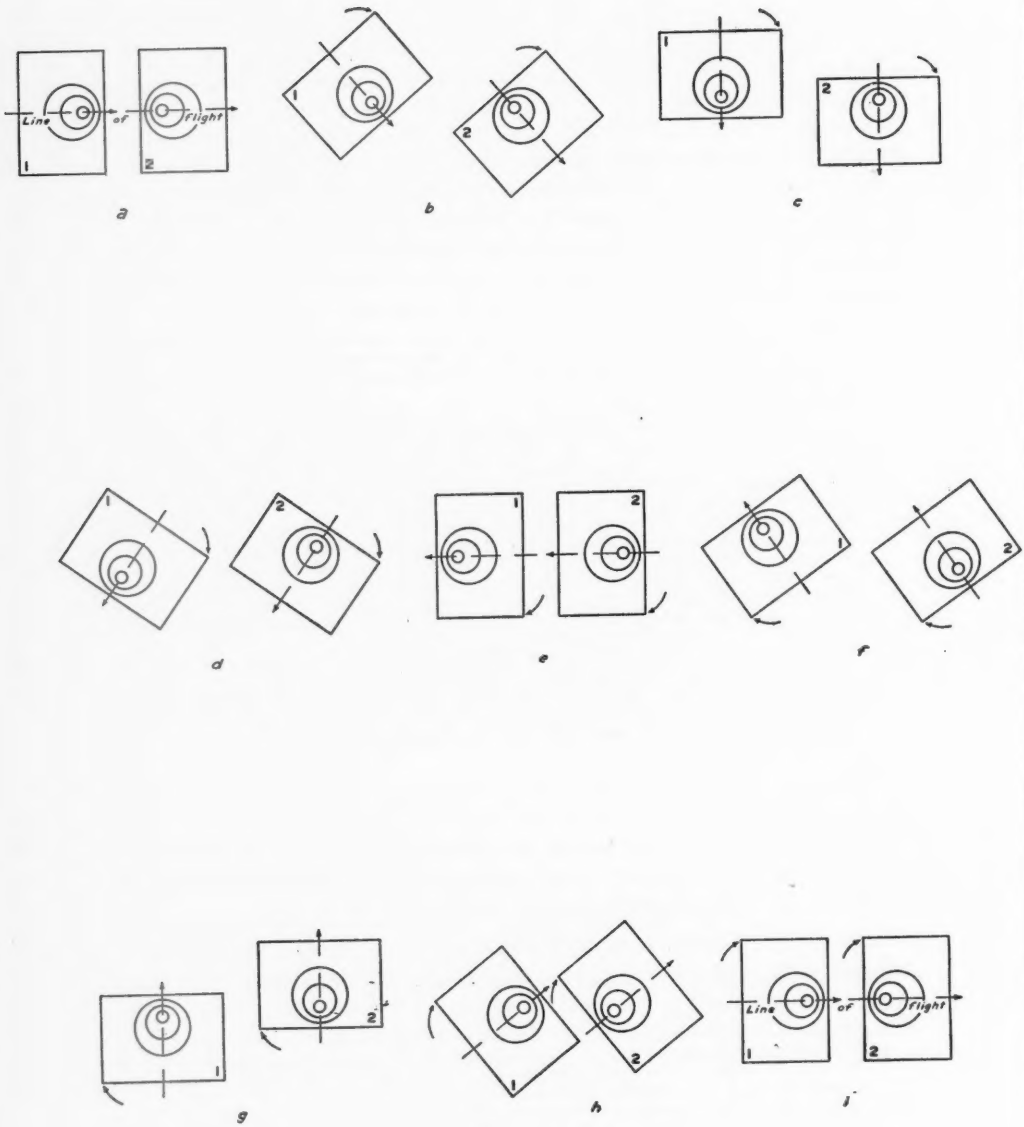

FIGURE 2

SHADOW EFFECT

It is a common belief that in viewing aerial photographs of hilly country, those hillsides in the sun-shadow must be oriented so that the sun appears to be above the observer's head. Failure to do this when one is viewing a single photo may lead inexperienced observers to "sense" the topography in reverse. More rarely it may cause the beginner when viewing a stereo-pair, to see even the stereoscopic image in reverse. However, those accustomed to using aerial photos will soon discover that, except in extremely rugged topography, the direction of the sun-shadow makes no appreciable difference. In fact, the full-time student of aerial photos, for ready comparison with maps, must frequently study them with the north direction "up" regardless of the direction of sun-shadows.

The vegetal growths on the protected north-facing hillsides (the "vegetal sun-shadow"), because they appear as dark areas, act much as a true sun-shadow in their effect on aerial photo study.

STEREOSCOPIC INSTRUMENTS

So much has been written about stereoscopes that it seems fitting for the writer to present merely the results of his experience in their geological use. This is perhaps best accomplished by lettering his observations in the order of their importance.

a. The geologist will want magnification in his stereoscopes, within the limit set by the size of grain in the pictures. It is true that in certain geological terrane, the formations and the structures are of such dimensions that they are clearly visible to the naked eye; yet in nearly every case certain important details will be visible only with magnification.

b. The geologist will need lenses of the highest quality. Since he will spend much of his time searching the photos for geological features near the limit of visibility, even the slightest irregularities and imperfections will introduce relatively great distortions. So far as the writer has been able to learn, lenses of high quality are not in common use.

c-d. The geologist will want bright illumination; and, during much of his study, will want to view the photos as close to the eye as is possible, consistent with clear vision. The reasons for these conclusions are the same as those supporting the foregoing statement ("a") about magnification.

e. The geologist will need a stereoscopic aid which is adjustable, or which has interchangeable lenses, for the varying width of overlap found in existing aerial photographs.

f. The geologist must have stereoscopes that can be used for many hours daily without undue physical or ocular strain. Stereoscopic spectacles remove much physical strain, such as that caused by prolonged bending over a table; but they may introduce certain distortions if the lens mount is flexible.

It seems clear that stereoscopes designed for geological use have not yet been developed. The existing magnifying stereoscopes are not of sufficiently high quality and are not adjustable for varying overlap. The available mirror stereoscopes place the observer too far from the photos and do not permit adequate illumination. Inventors of stereoscopic equipment are urged to give thought to the problems of the geologist.

VECTOGRAPHS AND ANAGLYPHS

Devices which use polarized light or complementary colors to secure a separation of the images of a stereo-pair of photos are of little use to the exploratory

geologist. They are very useful to illustrate geological ideas before large numbers of people. The expense, however, as well as the many opportunities for distortion during their manufacture, remove them, at present, from the class of aids to geological exploration.

PHOTO-INDEXES

A rough mosaic of contact prints, in which none of the photographic image has been trimmed away, is known as a photo-index. It serves the purpose of an index to the contact prints and to the lines of flight. Although the photo-index was not designed for such a purpose, it is found to have considerable geological value in certain regions. Two scales have been in common use—1 inch per mile and 2 inches per mile. The photo-index sheet at 2 inches per mile, if carefully made, is of greater use to the geologist than indexes at the smaller scale; though at the present time only the 1-inch scale is specified in the contracts let by the Agricultural Adjustment Agency and the Soil Conservation Service.

In the "plains" country, where the relief is low, photo-index sheets are good picture maps, and show a wealth of detail which is useful in many ways. Large structures in thick formations are clearly visible. On the other hand, stereoscopic vision is not possible with them and some detail is always lost in photographing and printing these sheets. In country of high relief, such as is found in most mountain ranges and in plateaus, the contact prints from the flight negatives cannot be matched well enough to construct index sheets which are usable by geologists. Where relief is one-tenth to one-third of the camera height above the ground, the distortions due to relief are very great. The top of a 4,000-foot hill, rising above a flat base and situated at the edge of the field of view, would be displaced the scale equivalent of approximately 2,300 feet away from its true position, if the field of view of the camera lens were 60°. Photo-indexes of geological value in regions of high relief, might be constructed by using lenses of long focal-length and by flying at heights much greater than has hitherto been done in most photographic mapping.

The discontinuities of photographic image, of tone, and of scale are a drawback in the use of photo-indexes. Yet since these discontinuities are perfectly obvious and uncamouflaged, the photo-index is in some respects safer to use than is the mosaic in which the arts of concealment must be employed. Good photo-index sheets of "low-strata-bench-lands" and true coastal-plain country are useful in geological exploration in proportion to the skill of the geological observer in interpreting drainage and topographic form.

MOSAICS

The disadvantage of abrupt discontinuities in photographic image, in tone, and in scale, which are so obvious in the photo-index, are also present to a smaller degree in most mosaics. In this case, however, such discontinuities are not obvious, and differences of tone and scale have been in large part eliminated. The

photo-matching which is important in the photo-index is of much greater importance in the mosaic. Here, it is frequently necessary to change the scale of contact prints from that of the flight negatives, and also to correct for tilt of the camera axis away from the vertical position. In addition, it has been necessary to develop the art of photo-matching, and to use all known means, including stretching and distortion, to produce a relatively continuous photographic image from the discontinuous pictures.

The best mosaics are quite expensive, since much labor is necessary to produce a picture map of constant scale. Even in these mosaics the photo-image and scale discontinuities are still present though so reduced in size that for engineering purposes they are insignificant. The procedures of (1) laying out the geodetic grid, (2) printing the best possible pictures for matching, and (3) tearing and camouflaging the torn edge, have been discussed in many publications. Here the writer is interested only in the resulting usefulness of mosaics for geological purposes.

To the geologist, the usefulness of a mosaic depends not so much on its constancy of scale as upon the way the photos were torn in matching one on another. If the photos are torn along natural objects such as hogback ridges, and narrow streams, to prevent the match being detected, the resulting mosaic may be of slight geological use. The geologist will be searching chiefly for signs of bedding (which at the prevailing scale of government photographs may be near or perhaps even beyond the limit of vision) and will very likely misinterpret any irregularity in photographic image. Mis-matchings that go unnoticed by the casual, though experienced, observer will in all probability be noticed by the geological observer studying the mosaic with a magnifying glass. Whether he notices the mis-match or whether he misinterprets its significance, it is still a hazard to the correct geological interpretation of the mosaic.

From his own experience in the geological interpretation of many kinds of aerial photographs, the writer recommends *that in laying mosaics of extensive areas, technicians with geological training be employed in matching the photos or, if this is impossible, in supervision of the work.* To do so may greatly increase the geological usefulness of the mosaic. In the rugged lands of the world where much aerial photography remains to be done, the mosaic may prove to be the only suitable device for securing a continuous picture map.

GEOLOGICAL CONCLUSIONS

In a field of thought and technology which touches many phases of geology, any brief remarks, though made with the best intentions, are sure to be a partial distortion of the truth. The following brief statements are no exception.

1. In mountainous terrane with thick lithologic units, the main structural irregularities stand out in great clearness. Accordingly the scale of photos is relatively unimportant. Drainage patterns may usually be relied upon to show the location, if not the exact nature, of structural features.

2. In mountainous terrane where structures, though steep, are small in relation to the thickness of lithologic units (as in a thick shale), neither drainage nor topographic form, considered separately or together, can be depended on exclusively for discovery of structures. Though there is ordinarily some genetic relationship, it is inconsistent from one locality to another.

3. In the "strata-bench-lands" of the world whether high or low (the plateaus and plains of some authors) as well as in those uncommon forms, the true depositional coastal plains, the drainage pattern alone, though important, can not be relied on for discovery. Experienced oil geologists know that there are commonly some drainage manifestations of local structure but they may not be consistent on neighboring structures.

4. Confusion may be introduced into topographic interpretation by the effects of weathering and erosion under the rigorous late Pleistocene climate of certain regions which are now much warmer and dryer. Other topographic "abnormalities" are very common in some regions, for example, creep and slump topography. The geological student of aerial photos will be compelled to spend much of his time learning to recognize the topographic effects of these so-called "abnormalities" in order that they may be subtracted from the composite topographic form. He will thus be better able to recognize the effects of bedrock stratification and thus to estimate the strike and dip.

5. Only experienced men with good eyesight will make much progress in the geological study of aerial photos. If larger-scale photographs become available the eye strain will not be so severe as at present.

6. When photos are used to construct good topographic maps, an expensive engineering problem arises. Ground surveying can not be eliminated or even much reduced, so great are the common distortions of the stereoscopic model.

7. The geological student of aerial photos will find that satisfactory progress depends not so much on an understanding of the physics, chemistry, and geometry of the pictures but chiefly on his ability to recognize bedding and to interpret the significance of topographic form correctly. More specifically he will have to recognize in the photos those geological features which simulate bedding but which are not bedding. To do this is very difficult in soft-rock terrane, because at 1/20,000 (the most common flight scale) the bedding at many places is invisible.

8. In unexplored regions, any geological method of exploration, including any type of oblique or vertical photography, will bring discoveries. Moreover, it is the writer's considered opinion that even where the search is difficult, aerial photos are of great value in the discovery of structures, though not necessarily in their detailed mapping. The exact degree of usefulness varies in different regions and is not yet too well known, for as yet but very few of the available photos have been made to the specifications of an experienced geologist or for geological purposes. The specifications thus far used were written mainly by engineers interested in the modification of water courses or in erosion and crop-acreage control. The pre-

vailing scale in the United States, of 1/20,000, is too small for geologic study in many regions.

As an experimental beginning in aerial photography for geological purposes the writer suggests: (1) that photographs for detail be made with a lens of 12-inch focal length, on a scale of 1/8,000 and that only the finest-grained film, and appropriate developing procedures be used; (2) that, in addition to such photographs for detail, high altitude photographs be taken at, say, 1/40,000 with a lens of 6-inch focal length. The best scale and focal length in each case will depend on the relief of the ground to be photographed.

9. The writer is very optimistic about the future of aerial photography for geological discovery, not only in the wilderness but in certain regions with a long history of exploration by other methods. Especially in its use for discovery, the expense of aerial photography will be negligible in comparison with its returns.

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PERMIAN WORD FORMATION: ITS FAUNAL AND STRATIGRAPHIC CORRELATIVES, TEXAS[1]

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ABSTRACT

The Permian Word formation and correlatives are widely distributed in Permian basin areas of Kansas, Oklahoma, Texas, and New Mexico. The formation includes strata that yield diversified assemblages of invertebrate fossils, among which at a locality the ammonoid *Perrinites* also occurs. Elements in these faunal assemblages are important for criteria that may be used to establish Word time-stratigraphic relationships with other middle Permian deposits elsewhere. It is now considered that Word strata are correlative with strata of the Cherry Canyon and the Brushy Canyon of the Delaware Mountain group, the San Andres group, the Blaine and the Dog Creek formations, of Permian basin areas.

INTRODUCTION

The Permian Word formation and its correlatives are distributed throughout Permian basin areas of Kansas, Oklahoma, Texas, and New Mexico, where these strata appear as outcrops whose tilted edges define basin areas, or they occur as subsurface deposits known only in drill cuttings from numerous wells that have penetrated these rocks in the search for oil and gas. Word correlatives have been recognized also in Mexico. The type Word geologic section is described for an area near the old Word Ranch house in the Glass Mountains of Brewster County, Texas, although lithogenetic and time-stratigraphic equivalents were recognized earlier in the Guadalupe and Delaware mountains, of Culberson County, Texas.

Some Word strata contain rich invertebrate faunas that have been studied by a number of geologists. These diversified assemblages continue to receive attention from geologists interested in Permian relationships, for Word paleontological criteria are doubtless determining factors in time-stratigraphic correlation for middle Permian strata. Recent studies of Word cephalopods, fusulinids, and the evidences from other invertebrates yield criteria that are new and pertinent in the endeavor to define time-stratigraphic relationships for the Word with other Permian deposits of Permian basin areas.

Since 1927, the writer on occasion has studied the stratigraphy and paleontology of the Word and associated formations in Texas and New Mexico. Criteria thus assembled, particularly from the more recent of these periodic investigations, are doubtless relevant to a broader understanding of middle Permian deposits. The writer reviews some of these evidences and suggests their application, the better to define Permian relationships. A description of such considerations and the criteria basic for them is the purpose of this paper.

The descriptive reference to the Word and its correlatives is extensive. Selective citation from this list of papers by geologists who have studied the middle

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and upper Permian merely serves convenience; mention is not made of all those authors to whom recognition is due. The writer nevertheless acknowledges his debt to those who have studied these strata.

GENERAL DISCUSSION

The Word formation was described by Udden,[3,4] and later by P. B. King.[5,6] The paleontology of the Word has been studied by Böse,[7] Smith,[8] R. E. King,[9] Plummer and Scott,[10] Dunbar and Skinner,[11] Miller and Furnish,[12] Newell,[13] King, Dunbar, Cloud and Miller,[14] and Miller.[15,16]

Early in June, 1945, the writer spent two days investigating the stratigraphy and paleontology of the Word and upper Leonard formations at the *type* Word locality near the old Word Ranch house, approximately 17 miles north-northeast of Marathon, Texas. Excellent exposures of these strata occur at this locality or adjacent to it, although strike and dip relationships of the outcrops change locally, due to folding accompanied by minor faulting. Here, the writer re-studied the paleontology of the first, the second and the third limestone members of the Word, and he measured two geologic sections of the upper Leonard and lower

[3] J. A. Udden, C. L. Baker and Emil Böse, "Review of the Geology of Texas," *Univ. Texas Bull. 44* (1916), p. 52.

[4] J. A. Udden, "Notes on the Geology of the Glass Mountains," *Univ. Texas Bull. 1753* (1917), pp. 46–53.

[5] P. B. King, "Geology of the Glass Mountains, Part I, Descriptive Geology," *Univ. Texas Bull. 3038* (1931), pp. 51–90, 131–45.

[6] ———, "Geology of the Marathon Region, Texas," *U. S. Geol. Survey Prof. Paper 187* (1937), pp. 98–104.

[7] Emil Böse, "The Permo-Carboniferous Ammonoids of the Glass Mountains, West Texas, and Their Stratigraphical Significance," *Univ. Texas Bull. 1762* (1917), pp. 1–241, Pls. 1–51.

[8] J. P. Smith, "The Transitional Permian Ammonoid Fauna of Texas," *Amer. Jour. Sci.*, 5th Ser., Vol. 17 (1929), pp. 63–80.

[9] R. E. King, "Geology of the Glass Mountains, Part II, Faunal Summary and Correlation of the Permian Formations, with Description of the Brachiopoda," *Univ. Texas Bull. 3042* (1931), pp. 1–240; 44 pls.

[10] F. B. Plummer and Gayle Scott, "Upper Paleozoic Ammonites in Texas," *Univ. Texas Bull. 3701* (1937), pp. 1–516; 41 pls.

[11] C. O. Dunbar and J. W. Skinner, "Permian Fusulinidae of Texas," *Univ. Texas Bull. 3701* (1937), pp. 517–825; 40 pls.

[12] A. K. Miller and W. M. Furnish, "Permian Ammonoids of the Guadalupe Mountains and Adjacent Areas," *Geol. Soc. America Spec. Paper 26* (1940), pp. 1–242; 44 pls.

[13] N. D. Newell, "Late Paleozoic Pelecypods; Pectinacea," *Kansas State Geol. Survey*, Vol. 10 (1937), pp. 58–60, 75–79, and 91.

[14] Robert E. King, Carl O. Dunbar, Preston E. Cloud, Jr., and A. K. Miller, "Geology and Paleontology of the Permian Area Northwest of Las Delicias Southwestern Coahuila, Mexico," *Geol. Soc. America Spec. Paper 52* (1944), pp. 7–23, 35–48, 71–130, Pls. 9–16, 20–45.

[15] A. K. Miller, "Some Exceptional Permian Ammonoids from West Texas," *Jour. Paleon.*, Vol. 19 (January, 1945), pp. 13–21.

[16] ———, "Permian Nautiloids from the Glass Mountains and the Sierra Diablo of West Texas," *ibid.*, Vol. 19 (May, 1945), pp. 282–94.

Word, whose strata compose the ridge escarpment that extends for more than 2 miles southwest from the old Word Ranch house. This ridge-like elevation is present on the northwest side of the road that leads to the old Word Ranch house.

The first measured geologic section was begun at the base of the cherty, conglomeratic upper Leonard limestones, which overlie the top of the Hess member of the Leonard that is exposed in the bed of the canyon at this locality. This section, from a point about 4,000 feet southwest (S. 42° W.) of the old Word Ranch house, was measured northward over the ridge escarpment and down the slope beyond, to about the middle of the silicified shale and sandstone exposures that overlie the very fossiliferous Word third limestone member. The measured section here agrees with geologic sections measured by P. B. King.[17]

A second geologic section of the Word was measured for comparative study at a locality from which the occurrence of an exceptional invertebrate assemblage had been noted and described.[18] The geologic section at this locality was begun near the north end of the earthen water-tank dam, on the northwest side of the road, about ½ mile southwest of the old Word Ranch house. This section, however, began in upper Leonard strata, about 30 feet below the base of the platy, bituminous limestone section of the Word first limestone member.[19] The section follows.

WORD FORMATION
(Top not exposed here)

	Thickness in Feet
8. Siliceous shales and sandstones, with 10-foot, fossiliferous, dolomitic limestone near middle	60
7. *Third limestone member.* Dark, cherty, fossiliferous, dolomitic limestone. Fusulinids numerous; *Parafusulina sellardsi* D & S, *P. wordensis* D & S	60
6. Siliceous shale, some fossiliferous, cherty dolomite and silicified sandstone	45
5. Gray dolomitic limestone, some siliceous shale	20
4. Siliceous sandy shale, some cherty, fossiliferous, dolomitic limestone	35
3. *Second limestone member*	
c. Gray, cherty, fossiliferous dolomitic limestone; *Waagenoceras* sp., *Parafusulina splendens* D & S and *Parafusulina* sp.	40
b. Siliceous shale and sandstone, weathers yellow to reddish brown	10
a. Dark, cherty, thick-bedded dolomite, fossiliferous in zones. Some inter-bedded thin, siliceous shale. Limestone surfaces weather rough and pitted	80
2. Siliceous shale and silicified sandstone, that weather yellow to reddish brown	20
1. *First limestone member*	
b. Gray, cherty, dolomitic limestone, dense to crystalline, slightly calcitic, with 8-foot bed of very cherty, dolomitic limestone in upper middle. Limestone surfaces weather rough and pitted. Limestone fossiliferous at several zones; *Perrinites* cf. *P. hilli* (Smith), *Pseudogastrioceras cf. P. texanum* Clifton, *Parafusulina bösei* D & S., *Parafusulina* sp., nautiloids, brachiopods, crinoids	85
a. Dark, thinly laminated, platy, dense bituminous limestone, weathers light gray	55

[17] P. B. King, *op. cit.* (1931), p. 72; p. 143, sec. 24; p. 144, sec. 26.

[18] A. K. Miller, *op. cit.* (January, 1945), pp. 13–21.

[19] P. B. King, *op. cit.* (1937), pp. 92, 101–04.

UPPER LEONARD FORMATION

1. Gray siliceous shale, some thin limestones, and 3-foot calcareous sandstone, 12 feet below top, and below base of word 30
(Top 30 feet only of upper Leonard exposed above bed of canyon)

Near the top of the ridge escarpment, on the northwest side of the road, approximately ½ mile southwest of the old Word Ranch house, and northwest of the earthen water-tank dam, the writer noted occurrences of casts and molds of invertebrate fossils at several zones in the gray, cherty, upper limestone section of the Word first limestone member. These invertebrate evidences were observed, not as continuous zones, in outcrops of the gray, cherty, limestone section for more than a mile west and northwest of the earthen water tank. These fossiliferous zones occur also at localities along the line of outcrops of these strata, southwest, to a point near Sullivan Peak, more than 10 miles from the old Word Ranch house.

Although fossil occurrences have been reported, the writer observed no invertebrate evidences in the underlying thinly laminated, bituminous, basal limestone section of the Word first limestone member, at the locality northwest of the road and near the earthen water tank, where the entire thickness of this bituminous limestone is well exposed in the sloping face of the ridge escarpment. The bituminous limestone section is overlain by the gray, cherty limestone section, whose strata form the upper part and the top of the elevation, at this locality.

The writer collected the following invertebrates from the gray cherty limestone upper section of the Word first limestone member near the top of the ridge northwest of the earthen water tank, on the northwest side of the road, about ½ mile southwest of the old Word Ranch house.

Perrinites cf. *P. hilli* (Smith)
Pseudogastrioceras cf. *P. texanum* Clifton
Ammonoid sp.
Nautiloids (two or more species)
Brachiopods (five or more species)
Fusulinids (numerous)
Parafusulina bösei Dunbar and Skinner
Parafusulina sp.

Approximately ½ mile farther west, the following were observed and collected.

Ammonoid sp.
Mooreoceras sp.
Nautiloid sp.
Pelecypod sp.
Gastropod sp.
Brachiopods (seven or more species)
Crinoids (numerous)
Fusulinids (numerous)
Parafusulina bösei Dunbar and Skinner
Parafusulina sp.

The invertebrates observed and collected by the writer, excepting *Perrinites* cf. *P. hilli* (Smith), are common to Word strata.[20] The writer, on former occa-

[20] P. B. King, *op. cit.* (1937), pp. 101–04.

sions, has collected *Medlicottia burkhardti* Böse, *Pseudogastrioceras*, and *Waagenoceras dieneri* Böse from strata of the Word first limestone member in outcrops near Sullivan Peak. These forms are common to strata of the second and the third limestone members of the Word at localities in the Glass Mountains, Texas. Conspecific or forms closely related to them have been observed and collected by the writer[21] elsewhere in Texas.

Credit for the discovery of *Perrinites* in strata of the Word first limestone member must go to G. A. Cooper of the United States National Museum, who collected them, and to A. K. Miller of the State University of Iowa, who gave notice of their discovery and described them.[22] Miller is not certain about the age of the limestone strata from which the *Perrinites* specimens come, though he believes the fossils are most probably from the upper part of the Leonard formation, and he formally assigns them, on zonal considerations, to the Leonard. Miller states:[23]

> There is no doubt as to the age of the strata that yielded most of the specimens discussed in this report. However, near the top of the slope on the northwest side of the road about one-half mile southwest of the old Word Ranch house in the Glass Mountains, Cooper collected the following cephalopods:
>
> *Mooreoceras?* sp.
> *Domatoceras?* sp.
> *Medlicottia whitneyi* Böse
> *Pseudogastrioceras cooperi*, n. sp.
> *Adrianites?* sp.
> *Stacheoceras* sp.
> *Perrinites hilli* (Smith)
>
> He believes that the beds from which this assemblage came are the lower limestone member of the Word formation, but he states that in the field he "felt that there was quite an overlap between the base of the Word and the top of the Leonard." Most of the cephalopods obtained at this horizon and locality are not very significant and could have come from either the Leonard or the Word. However, *Perrinites hilli*, which is abundant here, has for some years been regarded as characteristic of the Leonard and has never been found in the Word. It therefore seems to me that the beds which yielded these fossils are most probably in the upper part of the Leonard formation.

The ammonoid *Perrinites*, a common Leonard form, has been also considered a critical zone fossil. Occurrence, therefore, in younger Word strata presents a number of faunal implications quite significant to Word-Leonard relationships. The extended upward range of *Perrinites* into Word strata, where this ammonoid there occurs with sympatric species of *Pseudogastrioceras*, *Waagenoceras*, *Medlicottia*, and with fusulinids of the several species that ordinarily compose faunal elements in the fusulinid *Parafusulina rothi* assemblage, very obviously defines a number of middle Permian time-stratigraphic relationships, and likewise dis-

[21] R. L. Clifton, "Ammonoids from Upper Cherry Canyon of Delaware Mountain Group in Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (November, 1944), pp. 1644–48.

[22] A. K. Miller, *op. cit.* (January, 1945), pp. 13–21.

[23] A. K. Miller, *op. cit.* (January, 1945), pp. 14–15.

poses of what some geologists have regarded as problems[24] in correlation. The ammonoid *Perrinites* transcends the *type* Leonard of the Glass Mountains in Texas, though occurrences in younger strata from New Mexico and from east-side Permian basin areas, in Texas[25] and Oklahoma, had been earlier recognized.

CORRELATIVE CRITERIA

The *type* Word section has been described from exposures in the Glass Mountains of Texas, where Word strata have been divided[26] into two lithologic divisions, an upper and a lower Word.[27] Each of the limestone members that characterize the Word is important for diversified faunas, some elements of which appear in strata elsewhere in Permian basin areas.

Word lithogenetic and time-stratigraphic equivalencies have long been recognized[28] for some critical exposures in the Delaware and the Guadalupe mountains[29] of West Texas, that have been described as the Brushy Canyon and the Cherry Canyon formations[30] of the Delaware Mountain group. Elsewhere, Word correlatives, less perfectly understood, were recognized later in southeastern New Mexico,[31,32,33] that can now be correlated with the Brushy Canyon and the Cherry Canyon formations; Word time-stratigraphic equivalents that are known as the Blaine and the Dog Creek formations are present[34] on the east side of Permian basin areas in Oklahoma and Texas; and these Word equivalents are recognized in the intervening subsurface of Permian basin areas.

The Word is a well known cartographic unit that has been mapped for a local area in the Glass Mountains, Texas. Word lithogenetic and time-stratigraphic relationships can be critically studied from two main lines of evidences: (1) lithology and stratigraphic position, and (2), the faunas, primarily, the fusulinids and cephalopods. It is observed that fusulinids and cephalopods, which are present in many invertebrate assemblages at critical localities, are most useful fossil evidences, for determining Word relationships.

[24] P. B. King, "Permian of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (April, 1942), pp. 650–62, 668–72, 697–709.

[25] F. B. Plummer and Gayle Scott, *op. cit.* (1937), pp. 20–21, 85, 304–05, 317–19, 396–98.

[26] Frank E. Lewis, "Position of the San Andres Group, West Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25 (January, 1941), pp. 73–103.

[27] P. B. King, *op. cit.* (April, 1942), pp. 654–57.

[28] J. A. Udden, *op. cit.* (1917), p. 50.

[29] George H. Girty, "The Guadalupian Fauna," *U. S. Geol. Survey. Prof. Paper 58* (1908).

[30] P. B. King, *op. cit.* (April, 1942), pp. 576–81.

[31] Robin Willis, "Preliminary Correlation of the Texas and New Mexico Permian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13 (August, 1929), p. 1012.

[32] Robert I. Dickey, "Geologic Section from Fisher County through Andrews County, Texas, to Eddy County, New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (January, 1940) pp. 42–44.

[33] Frank E. Lewis, *op. cit.* (January, 1941), pp. 73–103.

[34] C. L. Mohr, "Subsurface Cross Section of Permian from Texas to Nebraska," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (November, 1939), pp. 1694–1711.

FUSULINIDS

The fusulinids, if they can be found, afford criteria that very well define Permian sequence and geography. Dunbar and Skinner[35] in their studies of the Fusulinidae have laid a firm basis for Permian correlation, the value of which increases with oil and gas development in Permian basin areas. Of present significance, Dunbar and Skinner have been able to subdivide middle and upper Permian, younger than Wolfcamp of Permian basin areas, into two major faunal zones on the basis of evolutionary stages displayed by the fusulinids. They define an upper zone of *Polydiexodina*, for fusulinids of final specializations, and a lower zone of *Parafusulina* for fusulinid occurrences in Texas and New Mexico.

Fusulinids of the genus *Parafusulina* have a great vertical range, through the Leonard and into the Word. Some geologists have found it feasible, on evolulutionary evidences, to subdivide approximately the zone of *Parafusulina* into a lower and an upper division. The fusulinid *Parafusulina rothi* Dunbar and Skinner characterizes the upper division, and this species with related forms constitutes a generally recognized *Parafusulina rothi* assemblage.

Fusulinids of the *Parafusulina rothi* assemblage, or upper division, are common to the Word and its correlatives. These fusulinids have been described by Dunbar and Skinner and others, from limestone members of the lower Word, and from the Brushy Canyon and Cherry Canyon formations of the Delaware Mountain group. These fusulinids are widely recognized from strata of the subsurface correlatives by petroleum geologists who study drill cuttings, incidental to oil and gas development. The fusulinid *Parafusulina rothi* Dunbar and Skinner has not been described from the Leonard, or from strata older than Word, in Permian basin areas.

Fusulinids have been collected by the writer in strata believed to be equivalent in age to the strata of the San Andres group at two critical localities in New Mexico, where fusulinid occurrence there is in strata that appear to be time-stratigraphic equivalents of the Word formation, and of the Brushy Canyon and Cherry Canyon formations. The genus *Parafusulina* is represented in these faunas by two or more species that are elements in the fusulinid *Parafusulina rothi* assemblage. *Parafusulina* cf. *P. maleyi* Dunbar and Skinner is identified by writer at both of these localities.

From one of these localities in Last Chance Canyon where Word-San Andres time-stratigraphic equivalents are well exposed, the writer collected fusulinids from strata chiefly of limestone and cherty dolomite that are present in the north wall of the canyon about $\frac{1}{2}$ mile northwest of the Lowe Ranch house, Eddy County, New Mexico. However, fusulinid occurrence there had been recognized earlier by Darton and Reeside and by Needham.[36] These fossiliferous strata collectively compose two general fusulinid zones. The lower one, about 100 feet thick,

[35] C. O. Dunbar and J. W. Skinner, *op. cit.* (1937), pp. 579–96, 672–99.

[36] C. E. Needham, "Some New Mexico Fusulinidae, "*New Mexico School of Mines Bull. 14* (1937), pp. 56–58, Pl. 11, Figs. 5–11.

overlies the platy, black limestone that is exposed just above the canyon floor at this locality. The second zone about 150 feet thick, occurs higher in the section, approximately 500 feet above the canyon floor, and extends to within 100 feet of the top of the canyon wall.

The lower fusulinid zone is important also for abundant occurrences of invertebrate fossils. Darton and Reeside have described two diversified faunas[37] from strata within this lower zone. The writer has collected one or more fusulinid species of the genus *Parafusulina* with other invertebrates, from these strata. The fusulinids that occur here doubtless represent elements in the *Parafusulina rothi* assemblage.

The upper fusulinid zone, composed of thick-bedded, dark dolomites and limestones, with much calcareous sandstone, is characterized by three or more strata in which fusulinids occur at places in crowded abundance. Some thin chert beds in massive dolomite and at bedding planes are also abundantly fossiliferous.

A 50-foot thick-bedded, dark, cherty dolomite, which composes the top of the second or upper fusulinid zone, yields an abundance of large forms that exhibit a somewhat higher order of internal development than that shown by fusulinids from strata underlying and composing the lower 100 feet of the second fusulinid zone. The fusulinids from this lower 100-foot section are assigned to the genus *Parafusulina* and they are elements in the *Parafusulina rothi* assemblage. The large fusulinids from the upper 50-foot section of dark cherty dolomite are assigned with reservation to the genus *Parafusulina*.

Fusulinid assemblages have been collected from strata of the San Andres group that overlie a gypsiferous zone of the Yeso formation, at a second critical locality in New Mexico. E. Russell Lloyd and the writer noted occurrences of fusulinids at a general locality along the common boundary of Sections 21 and 28, T. 23 S., R. 20 E., Otero County, New Mexico. Fusulinid occurrences here are in strata, exposed in the westward-facing, Dog Canyon fault escarpment, in the northern Guadalupe Mountains.

At this locality the writer collected fusulinids from three or more general zones; the top of the uppermost fusulinid zone occurs approximately 250 feet below the base of a sandstone that appears at the top of the fault escarpment. The base of the lowermost fusulinid occurrence lies about 150 feet above a gypsiferous section that appears near the top of the alluvial fan that covers the base of the great fault.

Fusulinid occurrence here is generally in zones within thick-bedded, reef-like[38] carbonate deposits. The fossiliferous dolomites are commonly cherty, and some thin beds of chert are crowded with fusulinid forms. From these assemblages, of

[37] N. H. Darton and J. B. Reeside, Jr., "Guadalupe Group," *Geol. Soc. America*, Vol. 37 (September, 1926), pp. 423–28.

[38] R. L. Clifton, *Unpublished Studies;* "Environment and Deposition: Concomitants in Late Middle and Upper Permian Seas," read before the North Texas Geological Society, February 21, 1945, Wichita Falls, Texas.

two or more species the writer has identified *Parafusulina* cf. *P. maleyi* Dunbar and Skinner, an element in the fusulinid *Parafusulina rothi* assemblage.

CEPHALOPODS

The cephalopods are not everywhere abundant but they are widely distributed in some strata of the Word and its correlatives. Among them, the nautiloids have been little used for critieria in stratigraphic determination, though they are important elements in Permian faunas. Nautiloid assemblages of diversified forms, by their association and occurrence in many places with ammonoids,

TABLE I

AN AMMONOID DISTRIBUTION AT CRITICAL LOCALITIES, OKLAHOMA, TEXAS, AND NEW MEXICO

	Lower Word, Glass Mountains, Texas		*Cherry Canyon, Delaware Mountain Group, Texas*	*San Andres Group, Sacramento Mountains, New Mexico*	*Blaine and Dog Creek, Pease River Group, Texas and Oklahoma*
	1st Limestone Member	*2d and 3d Members*			
Waagenoceras dierneri Böse	×	×	×		
Pseudogastrioceras roadense (Böse)		×	×		×
P. altudense (Böse)		×	×		
P. beedei (Plummer and Scott)		×	×	×	
P. serratum (Girty)		×	×		
P. texanum Clifton	×		×		×
Medlicottia whitneyi Böse	×				×
M. burkhardti Böse	×	×	×		×
Perrinites hilli (Smith)	×			×	×

doubtless afford criteria supplementing those from the more diagnostic ammonoid elements, in correlation.

The rich diversified, but interrelated, invertebrate faunas known from the four limestone members of the Word formation include some ammonoid elements that are important for affinities that occur elesewhere in Permian strata. Though important to Word lithogenetic relationships, the ammonoids are much more significant to considerations of *time-stratigraphic* equivalency for middle Permian deposits in Kansas, Oklahoma, Texas, and New Mexico. The ammonoid elements that are thus diagnostic of Word time-stratigraphic equivalency are listed for their occurrences at some critical outcrop localities in Table I.

STRATIGRAPHIC CONCLUSIONS

Great thicknesses of middle and upper Permian strata are well exhibited at many localities, perhaps nowhere better than in the Guadalupe Mountains of Texas and New Mexico. The Permian sequence is also recognized in subsurface drill cuttings and rock cores from numerous drill holes that have penetrated the

Permian section in the search for oil and gas. Wherever studied, Permian sequence in Permian basin areas is characteristically a lithologic succession that reflects the finality of environment[39] on deposition, which is evident in great reef-like carbonate deposits, for which the algae were largely responsible, and further evident in sandstones, interbedded with normally bedded limestones that also intergrade with reef-like carbonates, in some areas. Stratigraphical determination by lateral extension is possible, though not without difficulty, for such gradational sequences.

Recognized and generally accepted equivalency has been established for the east-side Pease River (El Reno) group with the San Andres group in New Mexico. Lewis[40] has shown that the San Andres group may be followed from the Sacramento Mountains southeastward to the Guadalupe Mountains, where San Andres strata grade into, and correlate with, the Brushy Canyon and the Cherry Canyon formations of the Delaware Mountain group, though Darton and Reeside[41] earlier expressed somewhat similar conclusions.

In intervening Permian basin areas equivalency for strata of the San Andres-Pease River groups has been established by Bybee,[42] Dickey,[43] Lewis and others in stratigraphical studies, based on the evidences from well logs and drill cuttings.

A better understanding of the Word and its lithogenetic and time-stratigraphic correlatives is also possible on the basis of paleontological criteria, chiefly from ammonoids and fusulinids. It is now known that the ammonoid *Perrinites* is present in strata of the lower Word, where *Waagenoceras dieneri*, *Pseudogastrioceras texanum*, *Medlicottia burkhardti*, and *Parafusulina* bösei, an element in the fusulinid *Parafusulina rothi* assemblage, also occur. It is now possible to recognize a Word faunal and time-stratigraphic sequence throughout Permian basin areas that includes strata within the Blaine and the Dog Creek formations, the San Andres group, the Cherry Canyon and the Brushy Canyon formations, the Word formation and their correlatives.

The ammonoid *Perrinites hilli* (Smith), an element common to the Blaine and Dog Creek formations, is known from San Andres strata at two localities in New Mexico. J. W. Beede collected this ammonoid in a stratum of the San Andres limestone section near Mountain Park, New Mexico. The writer collected *Perrinites hilli* (Smith)in outcrops of uppermost San Andres strata at a second locality 37 miles west of Artesia, New Mexico, where the occurrence of *Perrinites* is the highest known stratigraphic range for this ammonoid in America.

Perrinites hilli (Smith), known from the lower Word is conspecific with related forms (*P. vidriensis* Böse) that have long been known from the type

[39] R. L. Clifton, *Unpublished Studies, op. cit.* (February, 1945).

[40] Frank E. Lewis, *op. cit.* (January, 1941), pp. 80–83, 92–103.

[41] N. H. Darton and J. B. Reeside, Jr., *op. cit.* (September, 1926), pp. 413–28.

[42] H. P. Bybee *et al.*, "Detailed Cross Section from the Yates Area, Pecos County, Texas, into Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), pp. 1090–91.

[43] Robert I. Dickey, *op. cit.* (January, 1940), pp. 40–50.

Leonard of the Glass Mountains in Texas. A more primitive form and therefore older species, *Perrinites compressus* Böse (*P. hilli tardus* M & F), has been described from the Hess[44] formation (lower Leonard of P. B. King), of the Glass Mountains and also from the Bone Spring[45] formation of the Guadalupe Mountains in Texas. *Perrinites compressus* Böse is critical for correlative comparison with *P. hilli* (Smith) a younger species that has been described from the classic Croton Falls locality in Stonewall County, Texas.

Sympatric forms of the genus *Pseudogastrioceras* are widely distributed in strata of the Word and its time-stratigraphic correlatives, although *Pseudogastrioceras* occurrence in New Mexico, based on the writer's collections, is limited to two specimens. The writer collected *Pseudogastrioceras* cf. *P. beedei* (Plummer and Scott) in San Andres strata at a locality about ½ mile northeast of Cloudcroft, and he collected a poorly preserved *Pseudogastrioceras* specimen in San Andres outcrops at a locality about 6 miles east of Pinon, New Mexico. Species in the genus *Pseudogastrioceras* were trans-basin forms that doubtless were trans-ocean in origin to Word seas since none of these forms is known from strata of the underlying type Leonard formation, or its equivalents.

The writer suggests that nomenclatural usage for Word-Leonard relationships be re-defined, to include stratigraphically such diagnostic faunal elements as *Perrinites hilli*, *Waagenoceras dieneri*, *Pseudogastrioceras roadense*, *P. texanum*, and *Medlicottia burkhardti* in one time-stratigraphic unit or in a series, whose uppermost limit shall be defined by the base of the Whitehorse group of the Upper Permian.

In America the Permian system is divided into Lower, Middle and Upper. These are time-stratigraphic nomenclatural terms that are used by Paleontologists and stratigraphers[46] here and abroad. In America the ammonoid *Perrinites hilli* (Smith) characterizes the Middle Permian. This ammonoid, by occurrence and distribution, is a critical zone fossil that very well defines the Middle Pere mian in America.

[44] J. A. Udden, *op. cit.* (1917), pp. 43–46.

[45] A. K. Miller and W. M. Furnish, *op. cit.* (1940), pp. 154–55.

[46] A. K. Miller and W. M. Furnish, *op. cit.* (1940), p. 24, Fig. 2.

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GEOLOGICAL NOTES

PICKTON FIELD, HOPKINS COUNTY, TEXAS[1]

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The Pickton field is in southeastern Hopkins County, Texas, in the north-central part of the East Texas basin. It derives its name from the Pickton community which is approximately 1½ miles north of the field. It lies approximately 12 miles west of the New Hope field, which produces oil from three zones in the lower Glen Rose and one zone in the upper Travis Peak formation, and approximately 4 miles northeast of the Coke field, which produces oil from the Paluxy sands and gas and condensate from the lower Glen Rose.

As a result of subsurface closure mapped in this area, the Humble Oil and Refining Company made a detailed reflection-seismograph survey during 1942 which confirmed the Pickton structure as a low-relief anticlinal feature.

The discovery well, the Humble Oil and Refining Company's C. D. Nichols No. 1, located 660 feet north of the south line and 690 feet west of the east line of the C. D. Nichols tract in the Isaac Friddle Survey, was drilled to the total depth of 8853 feet, penetrating 313 feet of the Travis Peak formation. It was completed, November 6, 1944, through casing perforations from 7888 to 7896 feet opposite the porous oölitic Bacon limestone member of the lower Glen Rose. Its initial production was 620 barrels of 50.0° gravity brownish green oil in 24 hours, flowing through a ¼-inch positive choke, with a gas-oil ratio of 1349 cubic feet per barrel.

Subsurface markers as determined by the electrical log of the discovery well are as follows.

	Depth below Surface (Feet)	*Depth below Sea-Level (Feet)*
Top Nacatoch	1607	−1135
Top Pecan Gap	2494	−2022
Top Ector tongue of Austin	3940	−3468
Base Austin	4023	−3551
Top Woodbine	4556	−4084
Top Washita	5216	−4744
Top Fredericksburg	6038	−5566
Top Paluxy	6303	−5831
Top upper Glen Rose	6678	−6206
Top Ferry Lake anhydrite	7725	−7253
Base Ferry Lake anhydrite	7870	−7398
Bacon limestone (producing zone)	7870–7903	−7398–7431
Top Travis Peak	8540	−8068

The producing zone is the Bacon limestone which occurs at the top of the lower Glen Rose and underlies the Ferry Lake anhydrite. It consists of gray po-

[1] Published by permission of Humble Oil and Refining Company. Manuscript received, October 31, 1945.

[2] Geologist, Humble Oil and Refining Company.

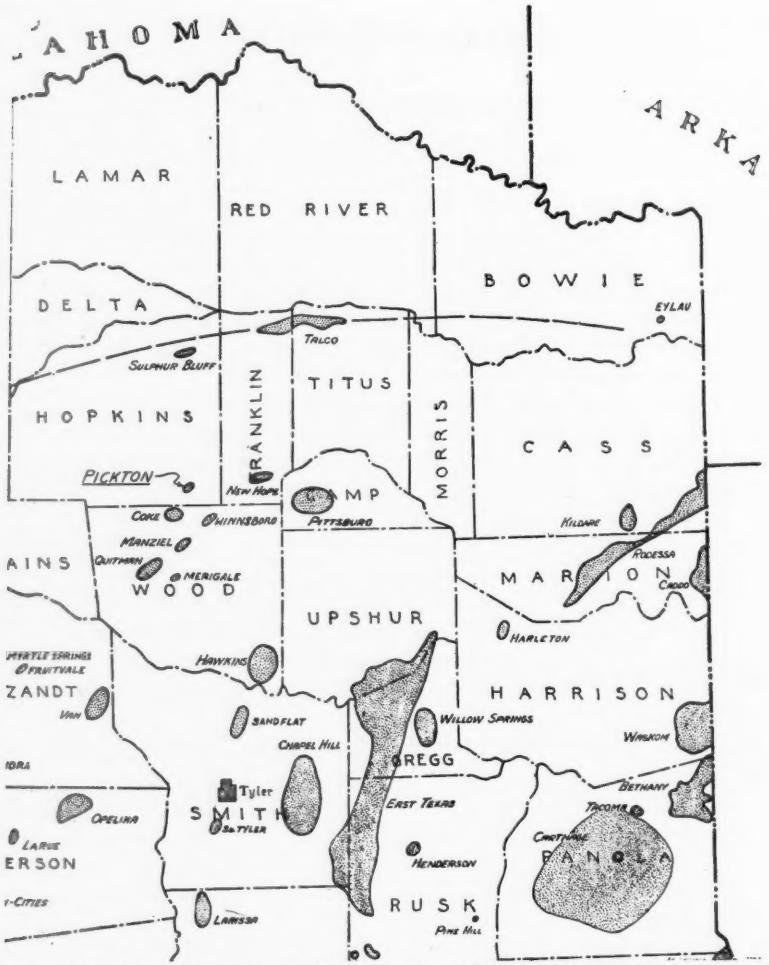

FIG. 1.—Map of northeastern Texas, showing location of Pickton field, Hopkins County, and its geographic relation to other fields. Scale, 1 inch equals approximately 40 miles.

rous fossiliferous oölitic limestone with dense gray argillaceous limestone at the base. It attains its maximum development near the center of the field and thins within a short distance toward the north. Two dry holes, the Sun Oil Company's E. L. Turner No. 1 and the Humble Oil and Refining Company's G. F. Baber No. 1, encountered thin sections of dense non-porous limestone in this zone on the north flank of the structure. It appears probable that the zone is missing entirely a short distance farther north.

The average thickness of the Bacon zone in the Pickton field is about 20 feet.

A limited number of core analyses indicates that the average porosity is about 18 per cent and the average permeability about 475 millidarcys.

The oil column as determined to date is 40 feet, and no free gas cap is known. The original bottom-hole pressure was 3578 pounds per square inch at 7424 feet subsea. The dissolved gas-oil ratio is 2220 cubic feet of gas per barrel of oil.

To date, 11 oil wells and 3 dry holes have been completed in the field, which is being developed on a 40-acre spacing program. When ultimately developed, the field will probably cover about 1500 acres.

MERIGALE FIELD, WOOD COUNTY, TEXAS[1]

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Tyler, Texas

The Merigale field is 1½ miles southeast of Quitman, the county seat of Wood County, Texas. Bobby Manziel's V. L. Evans No. 1, the discovery well, is 800 feet from the north line and 1800 feet from the east line of the Jeremiah Stark Survey. The pool was named in honor of the discoverer's baby daughter.

The field, which produces from the sub-Clarksville member of the Eagle Ford formation (Upper Cretaceous), is on the upthrown side of a northeast-southwest trending fault, downthrown on the northwest and having about 300 feet of throw. The fault trend in the area was first indicated by the drilling in August, 1943, of the Jackson and Fisher's O. M. McCarley No. 1, 5 miles northeast of Quitman. This test cut a 200-foot fault in the Eagle Ford and had showings of heavy black oil in both the sub-Clarksville and Woodbine. As a result, three additional holes were drilled in the immediate vicinity, but they were dry.

In June, 1944, the Allied Oil Company's Reba Chreitzberg No. 1, a mile south of Quitman, a 7500-foot Paluxy test, was abandoned as a dry hole after cutting a 300-foot fault below the sub-Clarksville in the Eagle Ford. This fault was proved to be the controlling fault in the Merigale field.

On December 17, 1944, Bobby Manziel, supported by the Shell Oil Company, Incorporated, completed his V. L. Evans No. 1 in the sub-Clarksville sand through perforations from 4860 to 4895 feet and 4914 to 4944 feet. The initial production was 32.6 barrels of 26.4° gravity oil in 10 hours on the pump, with a gas-oil ratio of 280 to 1. Since that time, four other wells have been completed, all in a line along the fault toward the southwest, extending production approximately 6000 feet. The most prolific producer to date is the Manziel's Shamburger No. 1, located 4000 feet southwest of the discovery well. This test had an initial production of 320 barrels of 30° gravity oil in 24 hours, flowing through a ¼-inch tubing choke, and having a gas-oil ratio of 390 to 1.

The producing zone, which is about 100 feet thick, is the sandy phase of the upper Eagle Ford, commonly referred to as the sub-Clarksville sand. It consists of broken laminae of sands and shales with here and there a sand body as much as

[1] Manuscript received, October 24, 1945.

[2] Shell Oil Company, Inc.

FIG. 1.—Index map showing location of Merigale field, Wood County, Texas, and its geographic relation to near-by fields. Salt domes are shaded.

10 feet thick. Its place in the section is about 50 feet below the base of the Austin chalk.

The typical stratigraphic section of the field is as follows.

Depth in Feet	
	Eocene
0–250	Claiborne
1000	Wilcox
1800	Midway
	Cretaceous
2450	Navarro (includes Nacatoch)
3800	Taylor (includes Pecan Gap)
4950	Austin chalk (includes Gober and Ector)
5000	Eagle Ford
5100	Sub-Clarksville sand
5525	Eagle Ford
6100	Woodbine
	Comanche
6200+	Buda limestone

At present the field has five producing wells and two drilling wells. About 200 acres have been proved for production. Though not expected to be a large field, the limits of production have not been established and a salt-water level has not been determined. The proved oil column to date is about 170 feet. A combination of subsurface and seismic work led to the discovery of this field.

COMBINED SURFACE AND SEISMIC EXPLORATION PARTY[1]

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Chula Vista, California

Many regions currently under exploration for possible petroleum-bearing structures are being worked both by surface and seismic parties. As these activities are generally undertaken independently of one another, there results a partial duplication of surveying and permitting, and a complete neglect of the data to be derived from correlation of samples available through the drilling of the seismic shotholes.

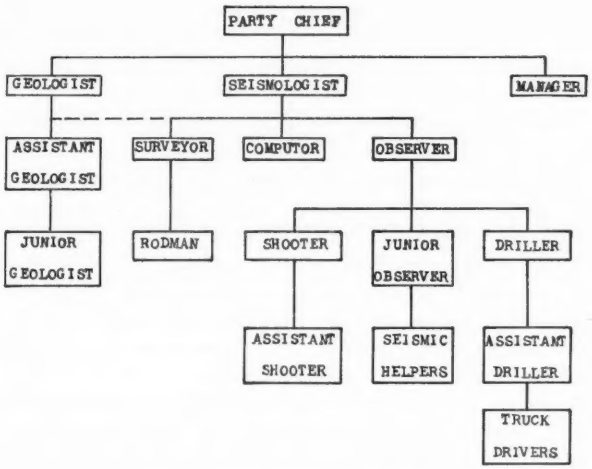

FIG. 1.—Chart of party organization.

If a single party were organized which would combine the functions of the surface and seismic parties and, in addition, provide for the collection and field study of shot-hole cores and cuttings, their data could be combined with the available subsurface data to make a complete areal and structural report. This procedure should be especially adaptable to large oil companies with broad exploration programs.

Although the combined party would allow of no reduction in personnel and would, in fact, require an extra man for the sample study, the surface work would be speeded with no retardation of the seismic program. The cooperation of field geologist and seismologist would permit no structural possibility to go untested and, with the aid of all local subsurface data, might make possible investigation of convergences and stratigraphic traps with a greater possibility of success than is now obtainable by seismic methods alone.

[1] Manuscript received, September 21, 1945.
[2] Loft mathematician, Rohr Aircraft Corporation, and consulting geophysicist. The writer expresses his appreciation to C. G. Bailey, of the Shell Oil Company, Inc., for his interest and helpful suggestions from his experience as a field geologist.

It might be well to note here that the addition of a junior geologist to collect and study shot-hole samples would provide one more opportunity for young geologists to gain valuable field experience.

From the organization chart (Fig. 1) the relation of the several departments within the party may be seen. Except for the position of "Junior Geologist," all of the titles are in common usage and the normal functions of their owners familiar.

The key position would, of course, be that of Party Chief. As administrative head he would direct the activities of the entire party. Technically he should be experienced in both seismic and geologic interpretation and thoroughly familiar with the theory as well as the field technique of each. His duties would include the final field correlation and interpretation of all seismic and geologic data, surface and subsurface, and the preparation of the field report.

Routine seismic interpretations and calculations would be performed by the Seismologist and Computor. The latter would also act as general draftsman for the party. Surface mapping would be done by the Field Geologist with his Assistant and the Junior Geologist.

If the Junior Geologist were provided with a "station wagon" or "carry-all" fitted with a microscope work-table, storage lockers, and other necessary petrographic field equipment, he could easily perform most of his correlations in the field while collecting his samples from the shot-hole drills. His car would also serve as a laboratory for the Field Geologist for the identification of questionable outcrops.

In addition to the routine surveying of shot-hole and geophone elevations and locations, the Surveyor would be responsible for all triangulation and control traverses required by the Field Geologist. This would speed the plane-table work of the Assistant and, thereby, more easily enable the surface mapping to keep abreast of the semismic program in rough and covered territory.

The activities of all the other members of the party would be normal. However, the Party Manager would be responsible for both the geologic and seismic personnel, and would be in charge of the maintenance of all the equipment. And, as permit man, he would obtain permission for all of the work, thus eliminating possible confusion in the minds of the landowners now caused by separate parties working for the same company. This would further free the Field Geologist for his mapping.

Summarizing briefly, we see that a combined surface and seismic party would prevent duplication of effort, utilize data now neglected, and provide a geologic and seismic picture most closely approximating the actual conditions.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

OPTIMUM PRODUCING RATES FOR ARBUCKLE LIMESTONE WELLS, BY P. T. AMSTUTZ, JR., AND EUGENE A. STEPHENSON

REVIEW BY ARNOLD S. BUNTE[1]
Roswell, New Mexico

"Optimum Producing Rates for Arbuckle Limestone Wells," by P. T. Amstutz, Jr., and Eugene A. Stephenson. *Univ. Kansas Pub., Research Foundation Bull. 1* (Lawrence, 1944).

This Bulletin is the result of an investigation undertaken by P. T. Amstutz, Jr., in 1940. It is written with a minimum of technical language and should be of interest to engineers, geologists, and production men wherever water is produced with oil, although it has been prepared primarily for the petroleum engineers and production men of Kansas. The authors secured the aid and cooperation of major and independent operators; they were given access to their well records and the actual use of their wells for experimental purposes. As a result, the reader feels assured of the accuracy of the data, as they are presented.

Bulletin No. 1 deals primarily with its subject matter. It offers a definition of optimum producing rate as the rate at which the withdrawal of oil is balanced by the inflow of water to the reservoir. In discussing the subject matter, a brief geologic consideration of the Arbuckle limestone is given with references to the outcrops in both Oklahoma and Missouri. This is followed by a description of the tests made on various wells to determine the desired data on water and oil production. In determining water content the "gauge pole" method is given just preference over "grind outs"; also the use of a single well as a unit is used rather than a battery served by several wells on the same lease. Water drives, water encroachment, other forms of water, and the effects of excessive withdrawal rates are discussed. Interesting data are given on the effects of variable permeability and the ever present danger of blocking off sections of oil, contained in blocks of low permeability. They also emphasize that high producing rates are conducive to the occlusion of oil in fine-grained lenses. The authors discuss pools under a water drive and emphasize that they should be operated at rates which minimize the reservoir pressure decline per unit of petroleum produced.

A chapter is offered on interference and gravitational displacement. The former is a well known occurrence in Kansas fields, not only in the "Arbuckle" reservoirs but also in "Viola" reservoirs. These data should be helpful to operators working on problems of well spacing. The part of the bulletin devoted to gravitational displacement will attract the interest of geologists as well as engineers.

All operators know the problems of producing water with oil. The costs of corrosion, water disposal, *et cetera*, are great, and, as a result, many methods are used to exclude or retard bottom-hole water. However, in spite of adverse results obtained in the laboratory, a method was tried by the authors to suppress the water cone and to oil saturate this water-bearing stratum contiguous to the well. This was done by injecting large quantities of crude oil into the oil-water reservoir. Thirteen wells of various ages and stages of water production were used in the experiment and, several months after the injected oil had been recovered, the water percentages were either eliminated or reduced. It is known that

[1] Vickers Petroleum Company, Inc. Review received, October 24, 1945.

fluid produced from a reservoir, whether water or oil, reduces the bottom-hole pressure and any method that will permit oil to be extracted with a minimum amount of water is bound to be beneficial to the reservoir. Excellent results have been obtained in Smackover limestone pools in Arkansas by injecting water back into the reservoir and by making the daily allowable to be total fluid rather than total oil. Perhaps the result of the Amstutz experiment is another step to produce oil more efficiently.

RECENT PUBLICATIONS

CALIFORNIA

*"Radiolaria from the Kreyenhagen Formation near Los Banos, California," by Bruce L. Clark and Arthur S. Campbell. *Geol. Soc. America Mem. 10* (New York, September, 1945). 66 pp., 7 pls.

CHINA

"The Natural Resources of China," by Chi-Yun Chang. *Pamphlet 1* (August, 1945). First of a series to further economic progress in China and other countries. Published by the Sino-International Economic Research Center, Inc., 86 Riverside Drive, New York 24, N. Y. Price, $0.30.

COLOMBIA

*"Development of Casabe Field," by E. Ospina-Racines. *Petrol. Engineer*, Vol. 17, No. 1 (Dallas, October, 1945), pp. 160–64; 3 photographs, 1 sketch map, 2 tables.

ECUADOR

*"Problemas del geologo a cargo del control geologico de subsuelo, durante la perforacion de pozos" (Problems of Geology and Care in Geological Control of Subsurface during Drilling of Wells), by R. L. Milner. *Bol. Inst. Sudamericano Petroleo*, Vol. 2, No. 1 Montevideo, August, 1945), pp. 102–12. Published by I. S. A. P., Av. Agraciada 1464, Piso 9, Montevideo, Uruguay. In Spanish.

*"Breves apuntes sobre la historia de la micropaleontologia en el Ecuador, durante los ultimos cincuenta anos" (Brief Notes on the History of Micropaleontology in Ecuador, during the Past 50 Years), by Hans E. Thalmann. *Ibid.*, pp. 113–19.

*"Tecnica y metodos de correlation micropaleontologicos en la geologia del petroleo" (Technique and Methods of Micropaleontological Correlation in Petroleum Geology), by Hans E. Thalmann. *Ibid.*, pp. 147–57.

GENERAL

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 12 (DECEMBER, 1945), PP. 1786-1793

THE ASSOCIATION ROUND TABLE

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NATIONAL SERVICE COMMITTEE PROGRAM[1]

F. L. AURIN[2]
Fort Worth, Texas

The details of organization and work of this committee have been outlined to all members of this committee, and they have been requested to disseminate this information through the local geological societies. Briefly, the national service committee has adopted a five-point program as its objective during the year.

1. Secure and organize the experience records of returning veterans, particularly those who have seen service in actual battle areas.
2. Keep abreast of changes in Selective Service regulations and be prepared to advise members who seek counsel of us on these matters.
3. Cooperate with other organizations in promoting the teaching and wider use of geology by the Armed Services, including the development of the criteria for military application and curricula for teaching same.
4. Keep informed on legislative and other developments and pronouncements which may have point for the profession.
5. Develop a program of effective assistance to members returning to civilian life to secure employment, where assistance may be proper, and especially assistance to those who, on account of physical injuries, may need counsel to adapt themselves to a change of status or duties in geological work.

The organization and roster of the national service committee is as follows.

F. L. AURIN, *chairman*

K. C. HEALD, *vice-chairman*, Veterans Experience Records, Pittsburgh, Pa.
M. G. GULLEY, *vice-chairman*, Special Activities, Pittsburgh, Pa.
A. R. DENISON, *vice-chairman*, Veterans Re-Employment, Tulsa, Okla.
W. B. HEROY, *vice-chairman*, Selective Service, Washington, D. C.
CHARLES B. HUNT, *vice-chairman*, Military Applications of Geology, U.S.G.S., Washington, D. C.

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John O. Galloway	Calgary, Alberta, Canada	Canada

[1] Manuscript received, November 8, 1945.

[2] Chairman, A.A.P.G. national service committee.

You will note from the foregoing organization and roster of the national service committee that there are five vice-chairmen who have the responsibility of carrying out the five-point program. It is our hope that you will feel free to contact them direct, or through your representative on the committee, for information or counsel on any subject coming within their jurisdiction; however, copies of all correspondence should be sent to the chairman of the national service committee.

A more detailed explanation of the functions of the vice-chairmen in the order of the five-point program is as follows.

1. K. C. Heald is vice-chairman of this activity. Practically all of this work is initiated by your general chairman, your representative on the committee, and the headquarters office. These experience records will be analyzed by K. C. Heald who, in turn, will cooperate with the vice-chairman on military applications of geology. This survey is one of the most important parts of our program. The appropriate committees in the affiliated geological societies, generally known as Military, War Effort, *et cetera*, and which have heretofore cooperated with the national service committee, are earnestly requested to cooperate with your district representative on the committee in assembling this information. These individual experience records should be sent direct to K. C. Heald.

There were at one time more than 700 members of A.A.P.G. in the Armed Services and out of that number we have a record in the headquarters office of the return of only about 100. It is our opinion that more than that number have returned but they have failed to notify the headquarters office. Any member returning to civilian status should do this promptly.

2. The vice-chairman on selective service regulations is W. B. Heroy who has already been very active in keeping up with the many changes in this respect, and such information as he has reported has already been passed on to the members of the national service committee. All information on future changes will be forwarded to them as soon as received. Many inquiries have been received on possibilities of the release of geologists who do not have sufficient points for release from the Armed Services when located in this country and overseas. Consult your representative on the national service committee for information in this respect.

3. The vice-chairman on teaching and military application of geology is Charles B. Hunt, who is the most outstanding and qualified man in our profession for this work. During the past three years he has been increasingly responsible for the development of military geology in the U. S. Geological Survey and, particularly, he has played an important part in selling geology to the Army. Your attention is directed to the articles appearing in the *Saturday Evening Post*, March 24, 1945, and *World Petroleum*, April 1, 1945, concerning the work of Mr. Hunt and his associates on the outstanding contributions of geology in World War II. During his recent tour of lectures on "Geology Applied to Military Intelligence" before the affiliated societies of the A.A.P.G. he gave a most complete and informative discussion on this subject. It was surprising to learn that he had started working several years ago on our Point No. 3. Mr. Hunt has been instructed to carry on this work (Point No. 3) with the assistance of as many members or consultants as he desires. It is indeed very fortunate for the profession, as well as for geology, that Mr. Hunt will serve on this committee.

4. The vice-chairman on keeping abreast of legislative and other developments which may have point for the profession is M. G. Gulley, and it is his responsibility to keep us informed on these subjects. It is not our objective or that of the Association to do anything to influence legislation on these matters.

5. We consider the objective on this part of our program an obligation of the highest importance. A. R. Denison is vice-chairman of this activity. He is located in Tulsa where he will be in close contact with the headquarters office where the records and other in-

formation on all members of the Association will be available to him. Several cases of our physically handicapped war veterans have come to our attention where the local geologists have taken a special interest in advising and suggesting the proper training to fit the veteran for some kind of geological work, even through such training would be of a different type from previous experience. This interest in such members should be encouraged in every case and we should do whatever is possible to keep them in geological work.

Another very important activity is to aid and assist returning veterans in seeking employment in geological work. In the case of those who were previously employed in geological work before entering the service, we should not encourage re-employment with a different company or a change of position with the former employer. In cases where his former job no longer exists and for those not previously employed we should help them to find employment in geological work. We should also keep in mind that, in so assisting, we or the Association assume no legal or other responsibilities.

The headquarters office will be the clearing house for both the applicant for employment and the prospective employer. In several late numbers of the *Bulletin* you probably have noted that there was a page announcement to the effect that companies or individuals are requested to list with the headquarters office any or all geological positions available. The applicants for employment should also contact the headquarters office in Tulsa, giving a brief history of their training and experience in geological work. In this connection, the members of the national service committee should contact and urge all companies and prospective employers in their areas to cooperate with the headquarters office. *Please keep in mind that the headquarters office is not running an employment service or agency*, as our principal objective is only to suggest possible opportunities for members and non-members of the Association.

In connection with the discussion of our five-point program you will note that our objectives have been changed in some respects from those of prior years. In addition to all of the foregoing, we should encourage the returning veterans who have not finished their geological training in college to resume that training with the aid of the provisions of the G. I. Bill of Rights. All returning veterans should be entirely familiar with the Bill of Rights and, if not, they can be referred to the proper authorities in each community.

If there is any question concerning our program, please feel free to call on the chairman or vice-chairmen at any time for any information pertaining to the work of this committee.

FOR AVAILABLE GEOLOGISTS

The Association invites oil companies and other employers who desire the services of geologists to list their needs with

A.A.P.G. HEADQUARTERS
BOX 979, TULSA 1, OKLAHOMA

The executive committee desires to remind the members and associates that the Association offers the facilities of the Headquarters office to those seeking employment. The committee desires in particular to offer its services to those who have served in the Armed Forces and are now released and seeking employment. File a complete record of your education and experience with J. P. D. Hull, business manager, Box 979, Tulsa, Oklahoma. He will bring your qualifications to the attention of those who have filed their needs with his office. A member of the national service committee will be available for counsel.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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MEMORIAL

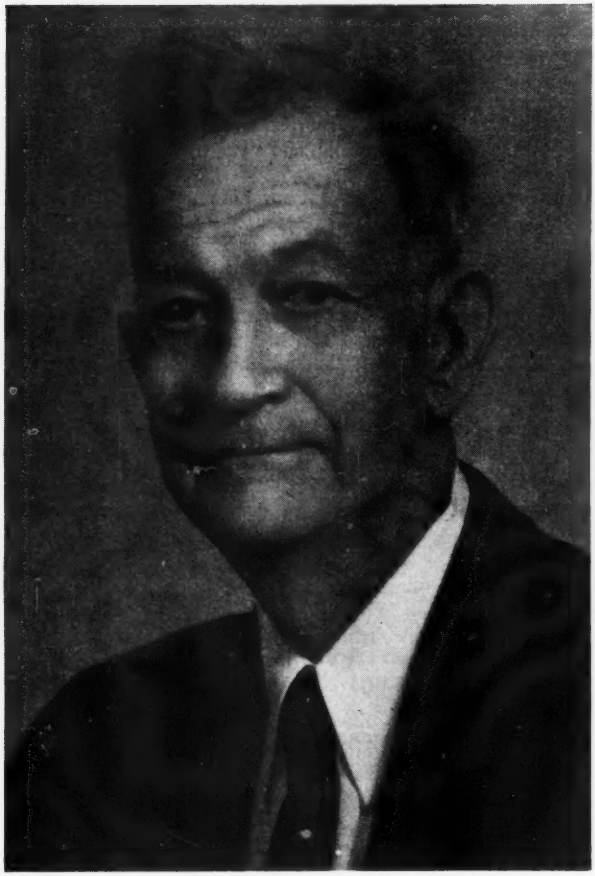
NOAH FIELDS DRAKE
(1864–1945)

Dr. Noah Fields Drake died suddenly of a heart attack in the late afternoon of May 4, 1945. He had been in his usual good health and had just returned from a business and pleasure trip to Tulsa, Oklahoma, early in the afternoon. His death removed one of the oldest and most widely known residents of northwest Arkansas. Dr. Drake was born on a farm near Summers, 20 miles west of Fayetteville, Arkansas, January 30, 1864. His grandparents had migrated from Virginia to establish their home in a region sparsely populated and primitive, the frontier of that early day. Dr. Drake's early education was in the rural schools near his home. He was graduated from the University of Arkansas with the degree of Civil Engineering in 1888, 14 years after the establishment of the University at Fayetteville. Following graduation, he joined the Arkansas Geological Survey for a year, where he came under the influence of Dr. J. C. Branner whose inspiration encouraged him to devote his life to geology. From 1888 to 1893 he pioneered in the geology of Texas on the State Geological Survey of that state, and also did geological work in the Indian Territory. Following Branner's resignation from the Arkansas Geological Survey and his removal to Leland Stanford University, Drake decided to follow. He was graduated from Stanford with the A.B. in 1894, the A.M. in 1895, and the Ph.D. degree in geology in 1897.

After graduation from Stanford in 1897, Dr. Drake joined the United States Geological Survey. He continued with that Survey for a year. Yielding to the pioneer spirit that actuated his forebears to leave Virginia and settle in a new land, young Drake decided to continue his professional work in China, an unknown country geologically at this early date. He accepted an appointment as professor of geology and mining at Pei Yang University, Tientsin, China, where he stayed two years. From 1900 to 1905, Dr. Drake pioneered in the geology of China, searching particularly for oil and other mineral resources. His work carried him into virtually unexplored parts of China attended with the usual hardships and dangers, including encounters with bandits. During this period, Dr. Drake completed a geologic reconnaissance of Tientsin, China, his map of the province being one of the first geological maps of any part of China. His work was recognized by the Chinese Government which awarded him three decorations at successive intervals. In 1905 he returned to Pei Yang University where he taught until 1911. Part of this time was devoted to further investigation of the geology and resources of China, his researches carrying him into every province of China. During 1900 and 1901, Dr. Drake was engineer for the Public Works Department of Tientsin, and from 1902 to 1904 he served as consulting geologist for the American China Development Company. He was chairman of the board of the Tientsin Land and Investment Company, Ltd., from 1904 to 1911, and in 1910 he was vice-president of the American Machinery and Export Company of Tientsin.

In 1911 Dr. Drake returned to California and accepted the associate professorship of economic geology at Stanford University. The next year he accepted the professorship of geology and mining at the University of Arkansas, retiring from active professional work in 1920 except for consulting work. During his tenure he did much to strengthen the department and forward the interest of the University.

Following his retirement from teaching, he became active in civic affairs and real estate development in Fayetteville. Several attractive homes in the northern suburbs of Fayetteville are a tribute to his architectural taste. The City Park with its large swimming pool resulted from his plans for the future of his home city. The first land for the Fayetteville airport was donated to the city by Dr. Drake. For years Dr. Drake was a member



NOAH FIELDS DRAKE

of the Fayetteville City Council. During much of this period he was chairman of the finance committee of the Council. Dr. Drake was also a leader in the local Chamber of Commerce.

Notwithstanding his many and varied interests in the city, Dr. Drake found time to devote to his farm a few miles north of Fayetteville. Here he specialized in fruit and grape culture. He was a pioneer in the culture of black walnuts, developing several new varieties with thin shells. His experiments attracted wide attention among walnut growers.

Dr. Drake was the author of numerous articles on the geology of Arkansas, Texas, California, and China, published in technical journals and the engineering press. His contributions to geology and his wide experience both here and abroad brought him numerous honors. He was an original member of the American Association of Petroleum Geologists, fellow of the Geological Society of America, member of the American Institute of Mining

and Metallurgical Engineers, Seismological Society of America, Royal Asiatic Society (North China Branch), China Philosophical Society, and the American Association for the Advancement of Science.

Dr. Drake was married to Mary Eleanor Shockley, June 30, 1904, who died on December 25, 1926. He was married to Lota West Fairchild, December 23, 1932, who survives. Two daughters of the first marriage also survive, Doris, the wife of Dean Robert A. Leflar of the University of Arkansas Law School, and Vera, the wife of Major Clifton Wade of the United States Army.

Dr. Drake was very modest and quiet, typical of many whose achievements and progressive ideas make them leaders in their community and profession. He rarely discussed his rich and interesting experiences spanning nearly a half century of professional work. His outstanding ability, integrity, kindness, and qualities of leadership were soon recognized wherever his many interests demanded his presence. In nearly 20 years of acquaintance the writer never heard him criticize anyone. His sudden and unexpected death was a shock to his community and to a host of friends. An able scientist, a pioneer in the geology of the West and of China, a civic leader, and a highly respected citizen has finished his life work. It was well done.

ALBERT W. GILES

FAYETTEVILLE, ARKANSAS
October 31, 1945

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 12 (DECEMBER, 1945), PP. 1797-1802

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The South American Petroleum Institute plans a meeting in Lima, Peru, in January, 1947, as announced by president CARLOS R. VEGH GARZON and secretary GERMAN E. VILLAR. This meeting, or congress, will consider the petroleum possibilities of South America.

EUGENE HOLMAN, president of the Standard Oil Company (New Jersey), has announced that the University of Oklahoma Foundation has accepted a grant of $15,000 to compile a history of oil in the Southwest.

FRED T. FERGUSON, formerly supervisor with the Brown Geophysical Company, Tallahassee, Florida, is now with the geological department of the Ohio Oil Company, and may be addressed at 701 East Park Avenue, Tallahassee, Florida.

CHARLES H. RANKIN, formerly with the Great Lakes Carbon Corporation is now associated with the Cameron-Transcal interests, active in Central Wyoming. Rankin is making his headquarters at Rock Springs.

Lieutenant EDWARD BENJAMIN BALDWIN, of El Paso, Texas, is reported deceased. He was in consulting practice at Houston before entering the Navy. His age was 47 years.

B. F. ANDERSON, formerly with the Gulf Refining Company, is in consulting geological practice at 320) Prairie Avenue, Mattoon, Illinois.

W. E. BAKKE, for the past 5 years petroleum geologist in charge of the oil loan department of the First National Bank of St. Louis, has resigned to reenter the oil business as a petroleum geologist and producer, and is now situated at 421 Milam Building, San Antonio, Texas.

M. M. MULHOLLAND, who for the past 3½ years has been stationed at the Tropical Oil Company's DeMares Concession as resident geologist, has been transferred to the exploration department in Bogota, Colombia.

J. ELMER THOMAS, consultant of Fort Worth, Texas, is in South America on a special mission for the *Oil Weekly*, of Houston. His itinerary includes Uruguay, Brazil, Argentina, Chile, Peru, and Ecuador.

WALTER E. HOPPER, consultant of Tulsa, was recently elected president of the Oklahoma Philatelic Society. In October he spoke on "Oil and Postage Stamps," at the meeting of the Tulsa Chapter of Nomads, and in December at a luncheon meeting of the Tulsa Geological Society.

C. E. NEEDHAM has been transferred from Washington, D. C., to Salt Lake City, Utah, as supervising engineer of that office of the Economics and Statistics Branch of the United States Bureau of Mines.

W. K. ESGEN has joined the Standard Oil Company of Egypt as head of the land and exploration department. His address is Box 607, Cairo, Egypt.

JAMES W. HUNTER has resumed work with the geological department of the Carter Oil Company, Shreveport, Louisiana, after an extended leave of absence due to illness.

LYNN JACOBSEN is with the Union Oil Company of California at Laramie, Wyoming.

MANLEY OSGOOD, JR., has resigned from the Cities Service Oil Company and has opened his office as consulting petroleum geologist. His address is 502 South Arnold Street, Mt. Pleasant, Michigan.

T. B. VANCE, formerly with the Texas Company at Mt. Pleasant, has become associated with the Panhandle Eastern Pipe Line Company, Box 512, East Lansing, Michigan.

WILLIAM BILLINGSLEA MILTON, JR., of the Houston Oil Company, Houston, Texas, died at the age of 40 years. He was recently president of the Houston Geological Society.

The geology department of New Mexico School of Mines and the State Bureau of Mines and Mineral Resources sponsored a fall field trip, October 20–21, in central New Mexico. More than 120 geologists attended, from Colorado, Oklahoma, Texas, and New Mexico. The registration was several times the largest pre-war figure. The first day's trip was through the Los Pinos Mountains and Chupadera Mesa, where stratigraphy and structure of Permian and Pennsylvanian strata were studied. On the second day the group drove to the top of a 9,200-foot peak in the Manzano Mountains to study the pre-Cambrian-Pennsylvanian contact and to discuss the regional structure of the Rio Grande and Estancia valleys. The excursion concluded with a visit to a well exposed thrust fault in Abo Canyon south of the Manzanos. The field trip was preceded by an open house Friday evening at the School of Mines. Those in charge of the trip were Professors GEORGES VORBE and RALPH H. WILPOLT of the Geology Department, School of Mines, and ROBERT L. BATES of the Oil and Gas Division, State Bureau of Mines and Mineral Resources. Able assistance in making arrangements was given by students of the School of Mines.

Lieutenant Colonel ROBERT B. WING, who was with the headquarters, Third Army, for 18 months in Europe, has returned to his work with the Shell Oil Company in Tulsa.

At the election meeting of the Wyoming Geological Association, Casper, Wyoming, the following officers were unanimously elected to serve from November 1, 1945, to October 31, 1946: president, WILLIAM H. CURRY, Atlantic Refining Company; 1st vice-president, ROBERT L. SIELAFF, Sinclair-Wyoming Oil Company; 2nd vice-president, P. W. REINHART, Shell Oil Company, Inc.; secretary-treasurer, DAVID T. HOENSHELL, General Petroleum Corporation. The address of the Association is Box 545, Casper, Wyoming.

The Southeastern Geological Society conducted a field trip in western Florida, November 9–10. Copies of the guidebook, composed of 93 mimeographed pages, a generalized stratigraphic column, a road map, and a geological map of Florida in colors, may be purchased at $3.00 per copy, by writing R. T. CHAPMAN, secretary-treasurer, Box 841, Tallahassee, Florida.

JOHN L. P. CAMPBELL, of the Lane-Wells Company, presented a paper on "Radioactivity Well Logging," at the meeting of the New Orleans Geological Society, November 5.

The Tulsa Geological Society and the Mid-Continent Section of the American Institute of Mining and Metallurgical Engineers met together, November 5, to hear JOHN H. MURRELL, of DeGolyer and MacNaughton, Dallas, on "Engineering and Geological Aspects of the Oil Fields of the Middle East."

SHELDON L. GLOVER is supervisor of the recently consolidated Division of Mines and Geology, 420 Transportation Building, Olympia, Washington. The postoffice address is Box 207. The office combines the former Division of Geology at Pullman and the Division of Mines and Mining at Olympia.

H. M. HOUGHTON has completed his work for the U. S. Engineers at the Loa Alamos Laboratories, Santa Fe, New Mexico, in connection with earth-shock measurements on the first Atomic Bomb, and is now employed by the Geotechnical Corporation at Bow Island, Alberta, Canada.

JOHN B. LUCKE has returned to his duties as associate professor of geology and head of the department of geology and geography at the University of Connecticut, Storrs, Connecticut. During the past year, as Lieutenant, U.S.N.R., he was photo-interpretation officer in charge of terrain and beach studies at the Joint Intelligence Center, Pacific Ocean Areas, Pearl Harbor, T. H.

After 2½ years in military service, LUIS E. KEMNITZER has resumed his practice as consulting geologist at his former offices at 704 South Spring Street, Los Angeles. Kemnitzer was economics, trade, and industry officer in Military Government and served in this capacity in England, France, and Germany. His last assignment was with the regional Military Government detachment for Bavaria with headquarters in Munich. His associate, L. W. Richards, has carried on the consulting work during the period that Kemnitzer was in the Army.

The Houston Geological Society had as guest speaker on November 5, JOHN T. LONSDALE, director of the Bureau of Economic Geology of Texas. Lonsdale's topic was "Post-War Program for the Bureau of Economic Geology."

JOHN C. DUNLAP, United States Geological Survey, who has been doing geologic work in the Southern Appalachians for the past 3 years, has been transferred to Carlsbad, New Mexico, to work on the potash deposits. His address is Box 829, Carlsbad.

M. R. SPAHR left the employ of the Carter Oil Company on October 1 and was employed by the Stanolind Oil and Gas Company on October 26, as subsurface geologist in the Houston district.

JAMES D. BERWICK is with the Rocky Mountain Land and Leasing Corporation, Pueblo, Colorado.

R. J. MONAGHAN left the Texas Petroleum Company in August and is now connected with the Phillips Venezuelan Oil Company at Barcelona, Venezuela.

Major WILLIAM PALEN CONWAY, JR., was killed in a plane crash in February, 1944. He was with the Hdq. 13th Air Force, Weather Station, San Francisco Post Office. Conway graduated from Princeton University in 1936, worked a few months as a geologist for the Anaconda Copper Mining Company at Butte, Montana, and since October, 1938, had been with the Phillips Petroleum Company, prior to joining the Air Force. He was 29 years of age.

The East Texas Geological Society sponsored a field trip, on December 1 and 2, to visit outcrops of Pecan Gap, Wolfe City, and Annona formations. Overnight stops were made at Greenville and Paris, Texas. A registration fee of $3 covered the cost of a guide book and a luncheon. Extra copies of guide book and map may be purchased at $2.00 by writing T. H. SHELBY, secretary-treasurer, Humble Oil and Refining Company, Tyler, Texas. G. W. PIRTLE is president of the Society, and C. I. ALEXANDER was chairman of the field-trip committee.

The San Joaquin Geological Society resumed its meetings on October 9. The officers of the society are: president, GLEN WALLACE LEDINGHAM, Western Gulf Oil Company; vice-president, J. DAVID CERKEL, JR., U. S. Geological Survey; secretary, HERMAN W.

WEDDLE, Standard Oil Company of California, Bakersfield. The feature talk at the first fall meeting was made by JAMES WARNER SHELLER, of the Richfield Oil Corporation, who told of his experiences while a captain in the Army Air Forces.

JOHN R. GISBURNE was released by the Navy on October 31. He has returned to the Shell Oil Company, Inc., and is situated at Oklahoma City, Oklahoma.

EDWARD V. O'ROURKE, professor of petroleum engineering at Ohio State University, Columbus, has been appointed director of the newly established Edwy R. Brown School of Petroleum at Marietta College, Marietta, Ohio.

ALBERT FOSTER CRIDER, consulting geologist of Shreveport, Louisiana, died last month at the age of 72 years. He was State geologist of Mississippi from 1906 to 1909 and the author of U. S. Geological Survey water-supply papers and bulletins, particularly *Bulletin 283*, "Geology and Mineral Resources of Mississippi," published in 1906.

The National Oil Scouts and Landmen's Association is scheduled to meet at the Hotel Heidelberg, Jackson, Mississippi, May 16–18, 1946.

United States Petroleum Resources, by J. Edgar Pew, vice-president of the Sun Oil Company, and chairman of the American Petroleum Institute, has been issued in pamphlet form. It is Pew's testimony of June 19, 1945, before the special committee of the United States Senate to investigate petroleum resources of the United States, Senator Joseph C. O'Mahoney, Chairman. The appendix of the booklet contains the report of the A.P.I. committee on petroleum reserves, made up of J. EDGAR PEW, R. F. BAKER, D. V. CARTER, FRANK R. CLARK, ALEXANDER DEUSSEN, G. CLARK GESTER, F. H. LAHEE, J. M. SANDS, FRED VAN COVERN, THERON WASSON, and FRED E. WOOD.

DONALD EGBERT FUELLHART, civil and petroleum engineer, died on October 23, 1945, at the age of 45 years. He had been with the firm of Brokaw, Dixon, Garner, and McKee since 1927. His recent address was Natchitoches, Louisiana.

The annual meeting of the A.I.M.E. will be held at the Palmer House, Chicago, February 25–28, 1946.

PHILIP ANDREWS, chief geologist for the Socony-Vacuum Oil Company of Colombia recently spent a few weeks in the states on business.

ROBERT R. OSBORNE, of San Antonio, Texas, died on January 5, 1945. He was connected with the Remo Oil Company and the Upland Oil Company. His age was 47 years.

New officers of the Pacific Section of the Association are: president, E. R. ATWILL, Union Oil Company of California; vice-president, VINCENT W. VANDIVER, Seaboard Oil Company; secretary-treasurer, ASHLY S. HOLSTON, Tide Water Associated Oil Company.

JOHN T. ISBERG has resigned from the Ohio Oil Company. He is employed by the Superior Oil Company at Bakersfield, California.

J. SMITH ADAIR, recently with the Lion Oil Company, El Dorado, Arkansas, is in the geological department of the Cabot Carbon Companies.

C. H. ACHESON has left Calgary, Alberta. He may be addressed in care of the International Ecuadorian Petroleum Company, Quayaquil, Ecuador, S. A.

GEORGE W. LA PEIRE is associated with W. E. Dunlap in consulting petroleum engineering. His address is 406 Subway Terminal Building, Los Angeles, California.

The fifty-eighth annual meeting of the Geological Society of America will be held Thursday, Friday, and Saturday, December 27, 28, 29, at the Hotel William Penn, Pittsburgh, Pennsylvania, under the auspices of the Pittsburgh Geological Society. Associated societies which will hold meetings in conjunction with the Geological Society of America are: the Paleontological Society, 37th annual meeting; the Mineralogical Society of America, 26th annual meeting; the Society of Economic Geologists, 26th annual meeting; and the Society of Vertebrate Paleontology, 5th annual meeting. Programs of vital interest to all geologists are being planned around the following principal topics: Geology in War and Peace, Geology in Engineering, the Geological Society's Obligations to Geologic Science and Public Welfare. All sessions are open to the general public.

R. B. PAXSON has left the Sunray Oil Corporation, Tulsa, Oklahoma, to open his office for consulting work in Houston, Texas, effective January 1, 1946.

EDWARD C. SIMPSON, formerly with the Superior Oil Company, Chico, California, is with the American Placers, Inc., Monravia, California.

KESSACK D. WHITE, petroleum geologist, may be addressed at Box G, Manteo, North Carolina.

DISTINGUISHED LECTURE TOURS

During November and early December two outstanding structural geologists visited 21 geological societies under the auspices of the distinguished lecture committee, in order to present their present interpretation of two diverse structural problems.

BAILEY WILLIS, emeritus professor of geology, Stanford University, appeared before a restricted group of societies in order to discuss his current thought on fundamental problems concerning forces active in the earth. His lecture on "Terrestrial Dynamics" encompassed all the accumulated wisdom of his many years of research and observation on structural movements, and was presented before the following societies.

November	9	Pacific Section, A. A. P. G., annual meeting at Los Angeles
	13	West Texas Geological Society at Midland
	15	Fort Worth Geological Society at Fort Worth
	16	Houston Geological Society at Houston
	19	Tulsa Geological Society at Tulsa
	21	Kansas Geological Society at Wichita
	23	Dallas Geological Society at Dallas
	26	Shreveport Geological Society at Shreveport
	28	Mississippi Geological Society at TACKSON
	30	Illinois Geological Society at Urbana
December	3	Pittsburgh Geological Society at Pittsburgh
	17	Rocky Mountain A. P. G. at Denver

CHESTER R. LONGWELL, chairman of the department of geology at Yale University, discussed the little-understood structure of the Colorado Plateau under the lecture subject, "Geology of the Basin Ranges: Revelations and Problems." During the lecture tour he visited the following societies.

November	5	Pittsburgh Geological Society at Pittsburgh
	8	Pacific Section, A. A. P. G., at Los Angeles
	12	Alberta Geological Society at Calgary
	15	Wyoming Geological Society at Casper
	16	Rocky Mountain A. P. G. at Denver
	17	Texas Technological College at Lubbock
	19	West Texas Geological Society at Midland

20 South Texas Geological Society at San Antonio
21 Houston Geological Society at Houston
23 Fort Worth Geological Society at Forth Worth
24 North Texas Geological Society at Wichita Falls
26 Dallas Geological Society at Dallas
27 Ardmore Geological Society at Ardmore
27 Oklahoma City Geological Society at Oklahoma City
28 Kansas Geological Society at Wichita
29 Ohio State University at Columbus
30 Appalachian Geological Society at Charleston

FRED H. MOORE, *Chairman*
Distinguished Lecture Committee

UNITED STATES GEOLOGICAL SURVEY STAFF CHANGES

Director W. E. WRATHER, of the United States Geological Survey, has announced recent organizational changes within the Geologic Branch of the Survey, which is headed by chief geologist W. H. BRADLEY.

The Geologic Branch has been subdivided into two Divisions and a Technical Service and Administrative Group. H. M. BANNERMAN has been named chief of the Division of Economic Geology. During most of the war period he served as chief of the Section of Non-Metallic Minerals.

H. S. LADD has been designated chief of the Division of Areal Geology and Basic Sciences. He was formerly regional geologist, in charge of the Rolla, Missouri, office of the Survey. J. W. PEOPLES, assistant chief geologist, has been named head of the Technical and Administrative Group.

A Special Research Staff has been set up within the Geologic Branch, having advisory function in connection with long-range research planning and Branch policies. This staff includes D. F. HEWETT, G. F. LOUGHLIN, and W. W. RUBEY. Other geologists are temporarily assigned to this staff as the planning needs dictate.

A new Section of Geologic Information and Reports has been established. DON L. CARROLL, until recently foreign editor and staff geologist of the *Oil Weekly*, has been designated chief of the new section.

The following sections now comprise the Division of Economic Geology:
Geology of Fuels: H. D. MISER, chief
Geology of Metalliferous Deposits: CHARLES F. PARK, JR., chief
Geology of Non-Metalliferous Deposits: JOSIAH BRIDGE, acting chief
Foreign Geology: J. V. N. DORR 2ND, acting chief

Within the Division of Areal Geology and Basic Sciences are included the following sections.
Areal Geology: J. T. HACK, acting chief
Engineering Geology: E. C. ECKEL, chief
Chemistry and Physics: W. T. SCHALLER, chief
Paleontology and Stratigraphy: J. B. REESIDE, JR., chief
Petrology: C. S. ROSS, chief
Military Geology: E. S. LARSEN, 3RD, acting chief
Geophysics: J. R. BALSLEY, acting chief

The Technical Service and Administrative Group includes the following units.
Manuscript Review Board: C. H. DANE, chairman
Geologic Map Editor: E. N. GODDARD
Geologic Cartography: L. B. PUSEY, chief
Committee of Geologic Names: Miss FRANCES WILLOUGHBY, secretary
Office of the Chief Clerk: Mrs. A. L. BROWN, chief

Changes in field assignments have also been announced. A. L. WEISSENBORN, of the Rolla, Missouri office, has been designated as regional geologist at Spokane, Washington. ROBERT A. LAURENCE has been made eastern regional geologist, with temporary headquarters at Jefferson City, Tennessee. CHARLES B. HUNT, formerly chief of the Military Geology Unit, has been designated regional geologist at Salt Lake City.

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Page 530, 2d paragraph, 1st line. "Fig. 12" should be Fig. 23.

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Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

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Treasurer - - - - - - - - P. F. Haberstick

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

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Consulting, 502 S. Arnold St., Mt. Pleasant
Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

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Stanolind Oil and Gas Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

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Gulf Oil Corporation, Box 30

Secretary-Treasurer - - Hamilton M. Johnson
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

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OKLAHOMA CITY, OKLAHOMA

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1216 Petroleum Building

Vice-President - - - - - - Roy D. McAninch
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Secretary-Treasurer - - - - - Carl A. Moore
Carter Oil Company
1300 Apco Tower

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second Wednesday, at 12:00 noon. Skirvin Hotel.

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Oklahoma Seismograph Company

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Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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U. S. Geological Survey, Box 311

Editor - - - - - - - - Charles J. Deegan
Oil and Gas Journal, Box 1260

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

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Barnsdall Oil Company, 604 Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

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Executive Committee - - - Henry J. Morgan
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Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

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Hudnall & Pirtle, Peoples Bank Building

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Tide Water Associated—Seaboard Oil Companies

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Luncheons: Each week, Monday noon, Blackstone Hotel.

Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

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Stanolind Oil and Gas Company, Box 1410

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Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

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Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

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Magnolia Petroleum Co., Box 239

Vice-President - - - - Charles R. Canfield
Stanolind Oil and Gas Company
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Secretary-Treasurer - - - - John R. Davis
Superior Oil Company, 807 Hamilton Building

Luncheons and evening programs will be announced.

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1409 Milam Building

Vice-President - - - - - - George H. Coates
638 Milam Building

Secretary-Treasurer - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

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United Fuel Gas Company, Box 1273

Editor - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

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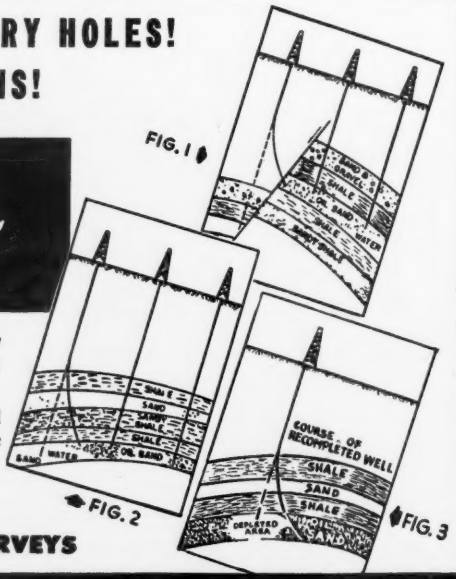

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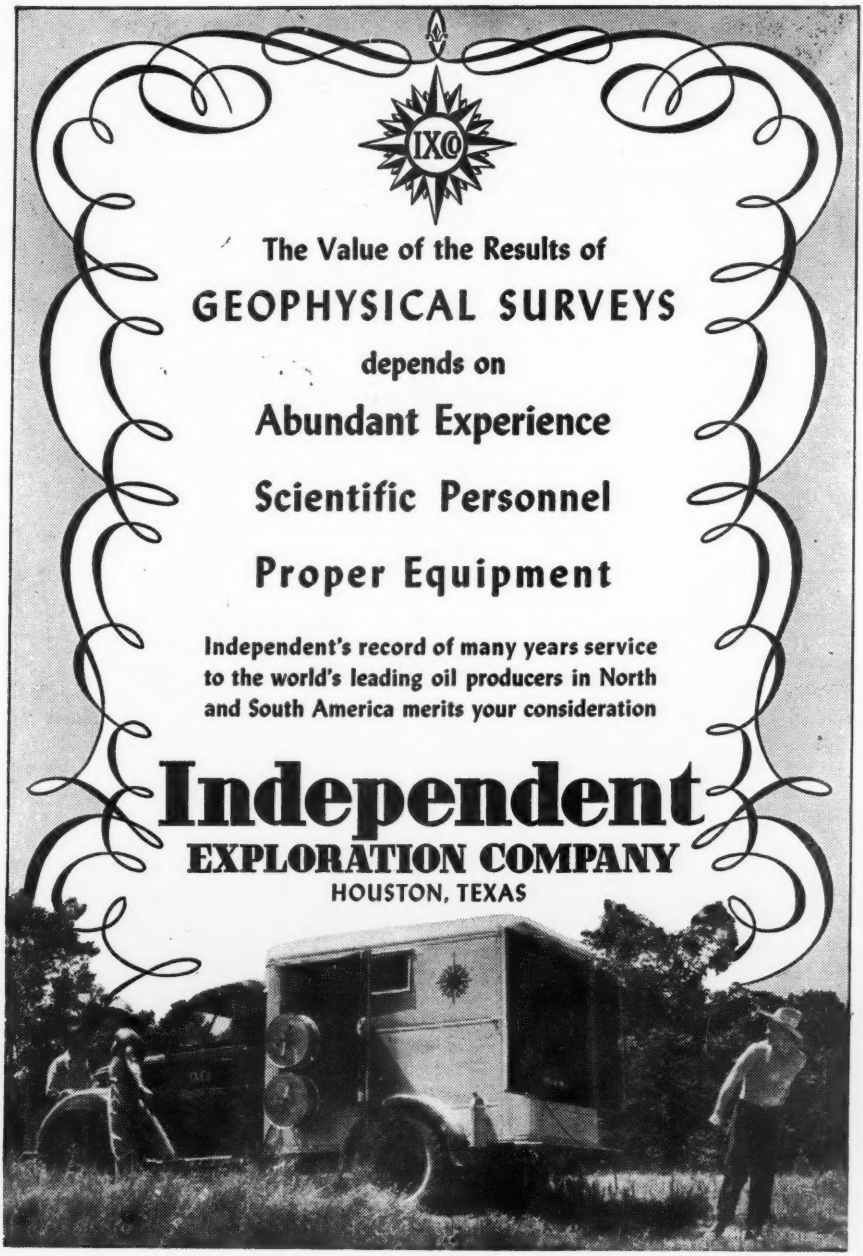
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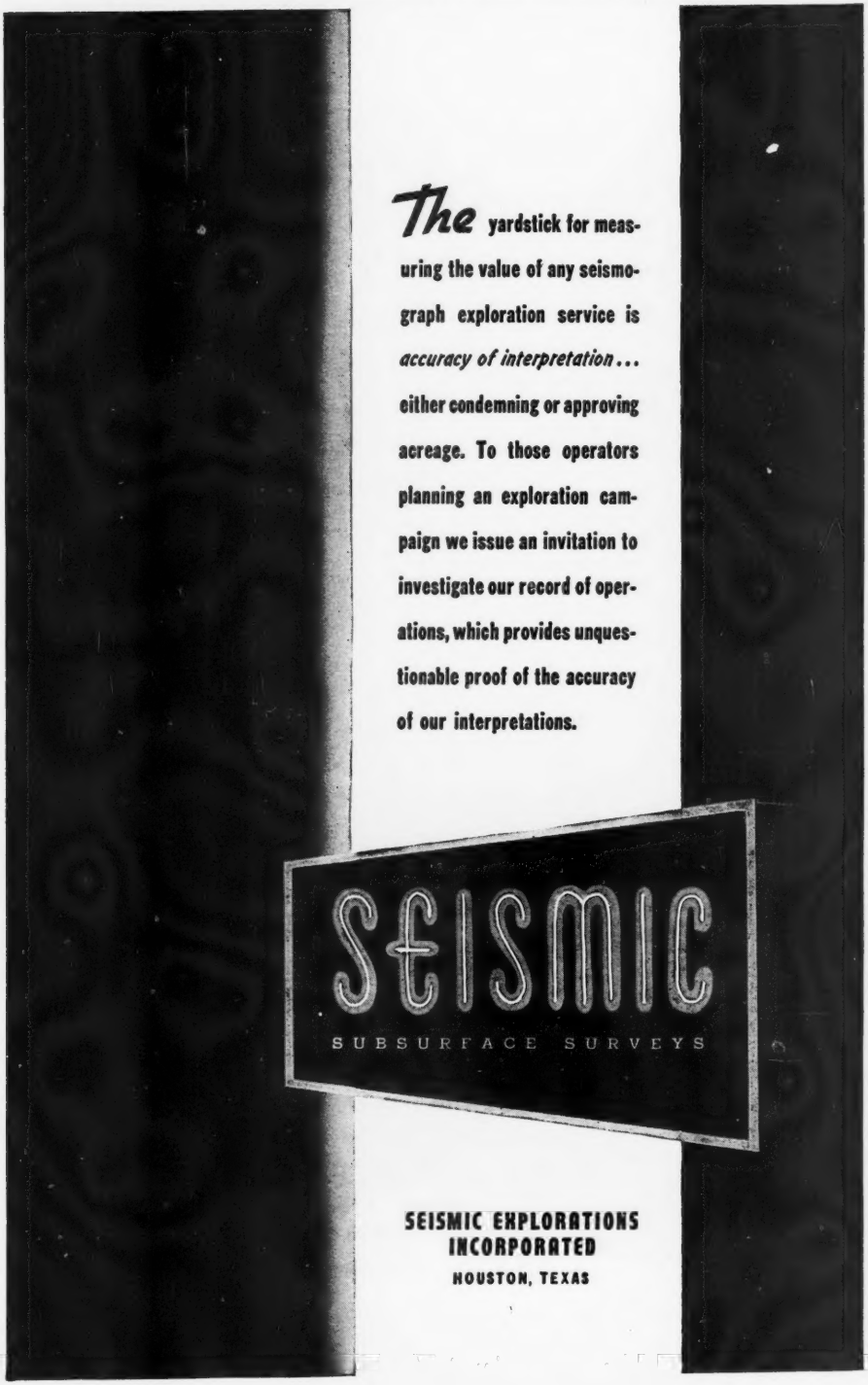

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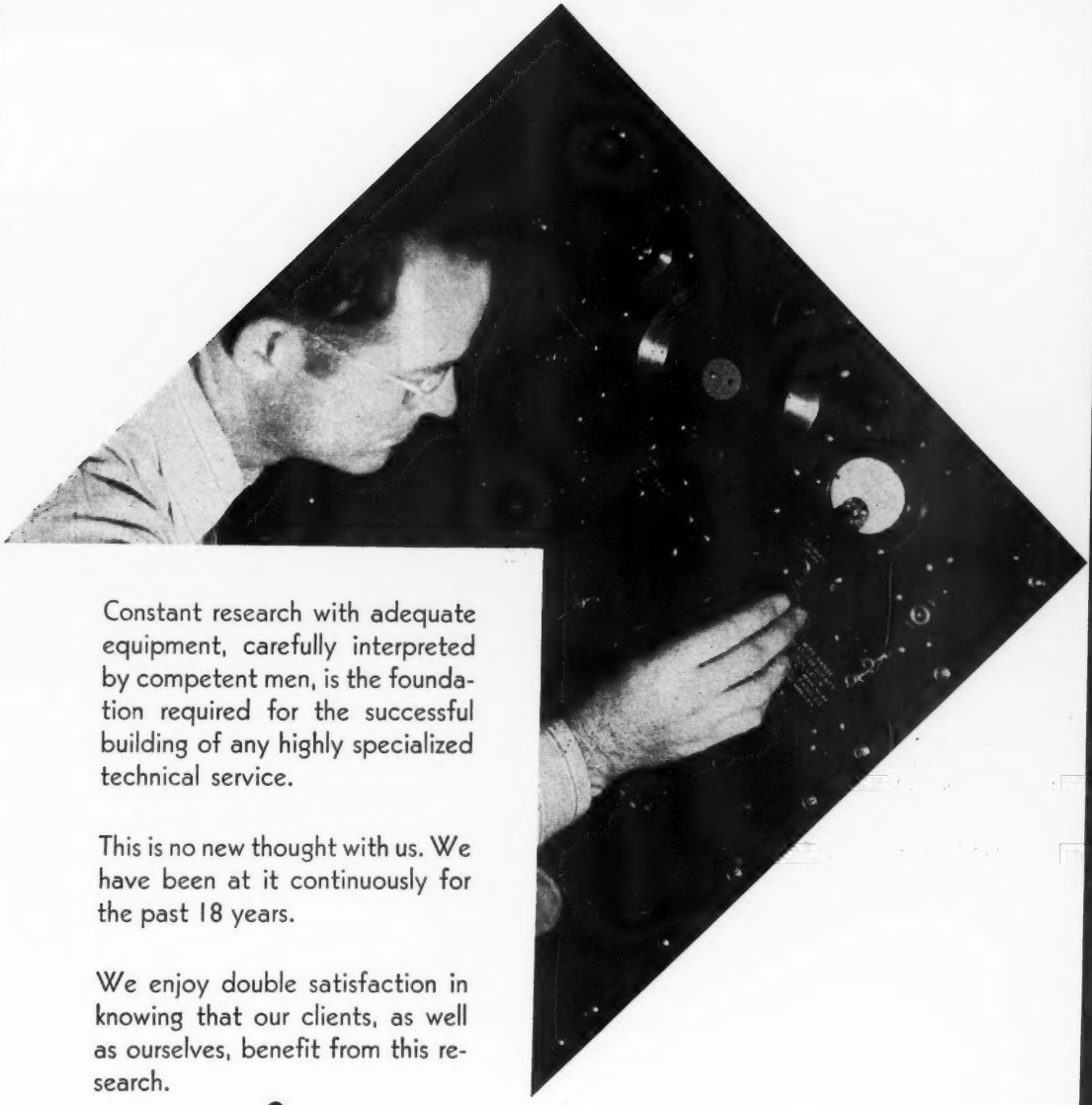

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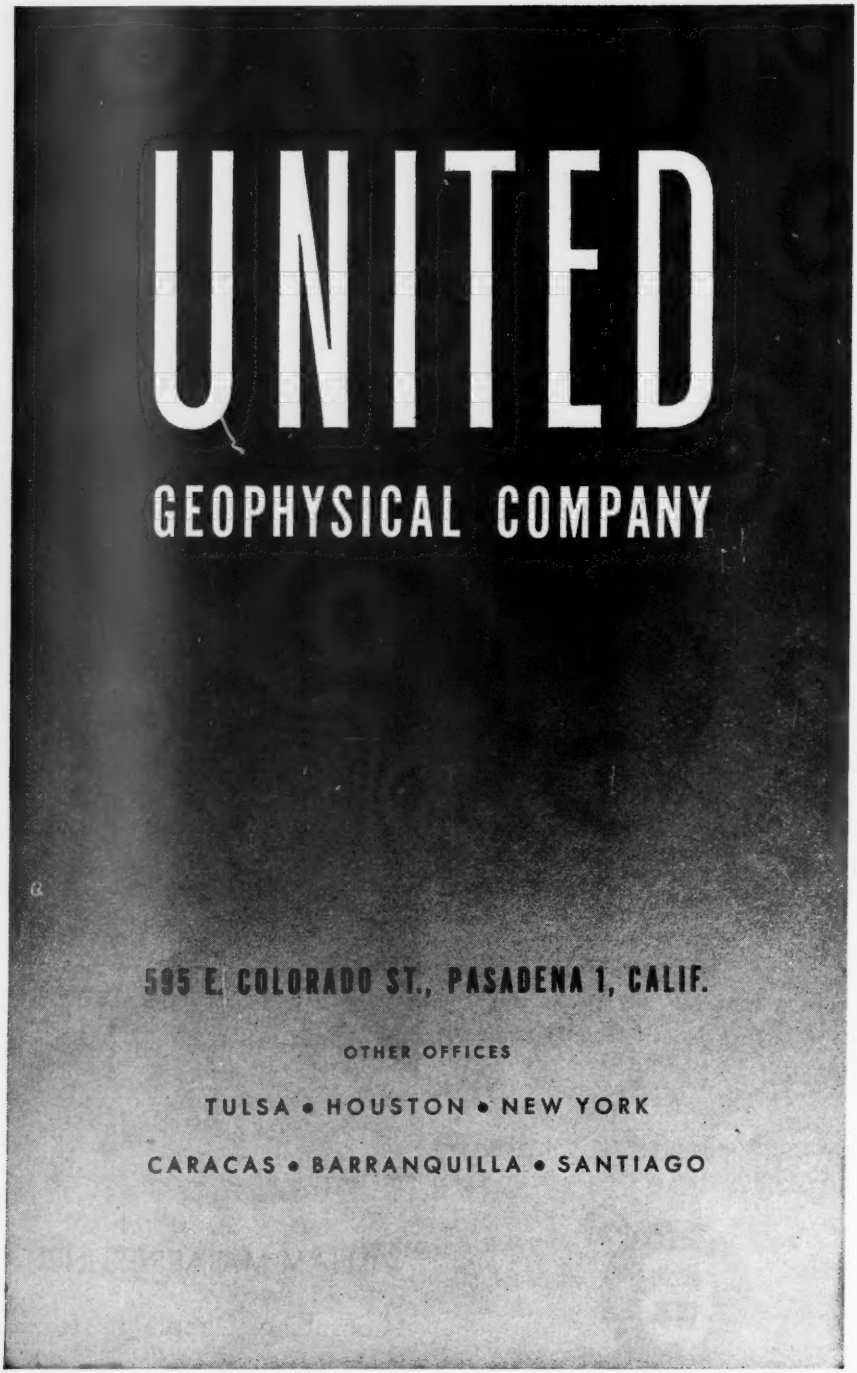
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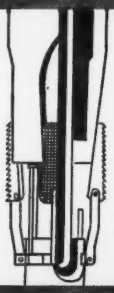

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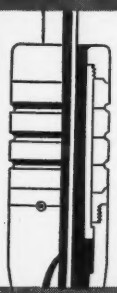

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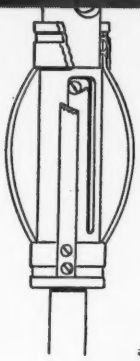

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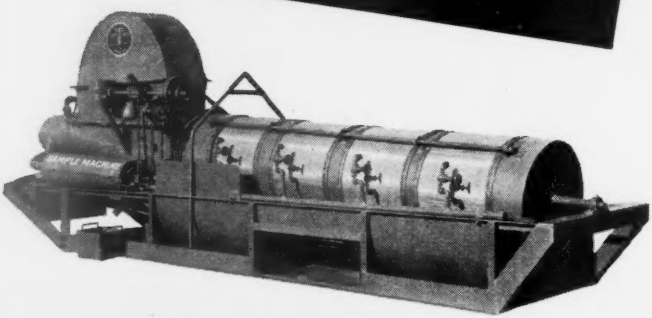

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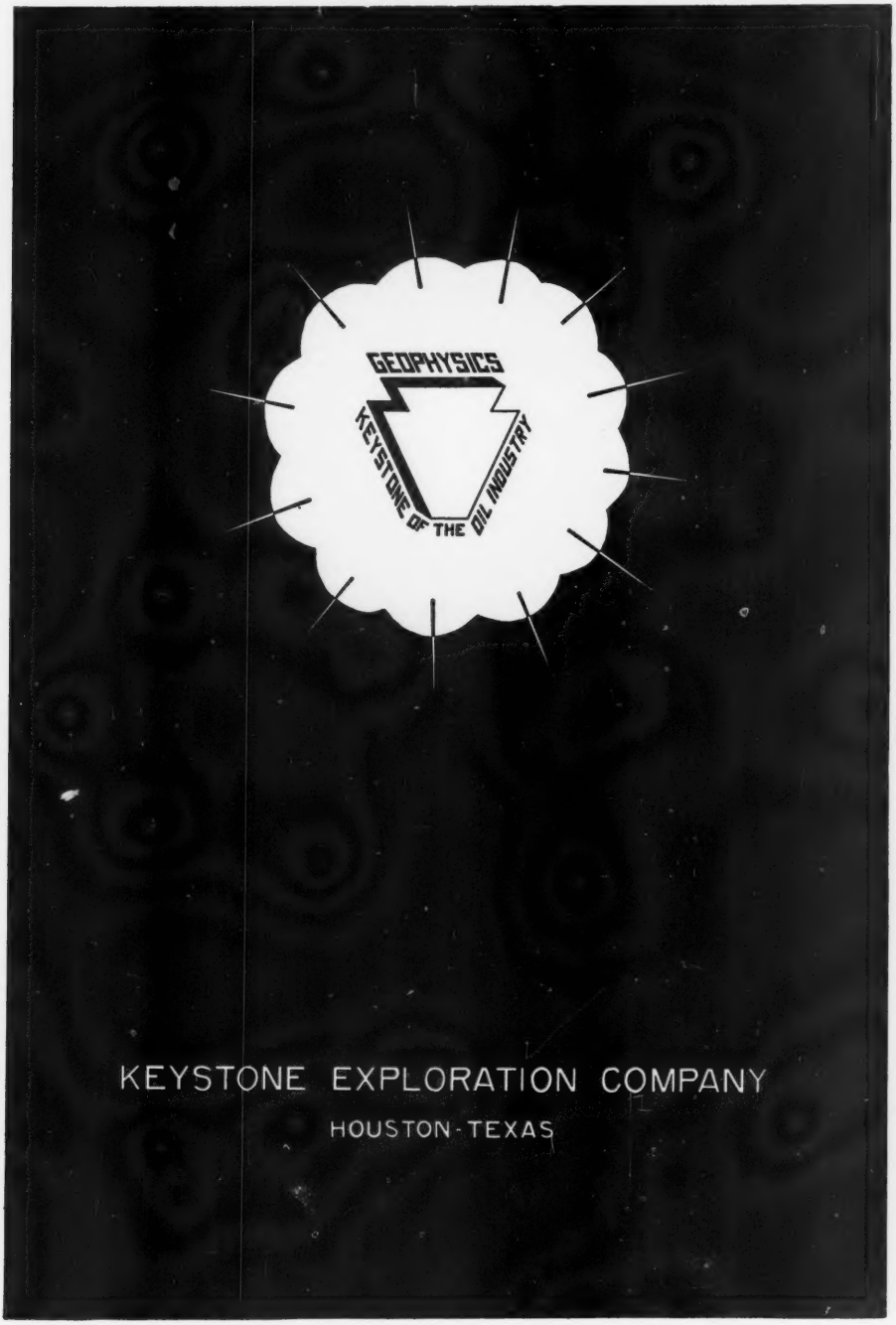
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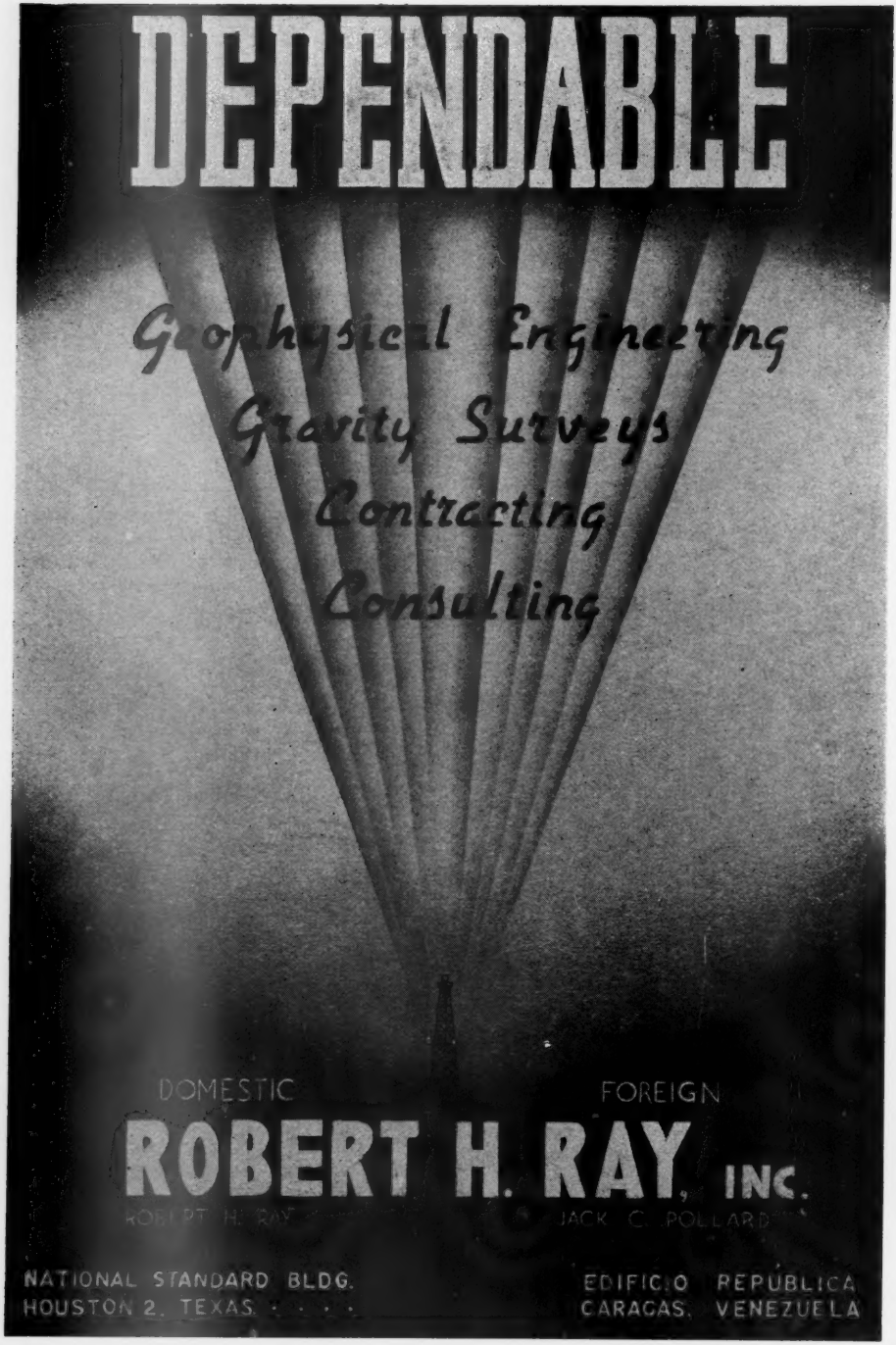
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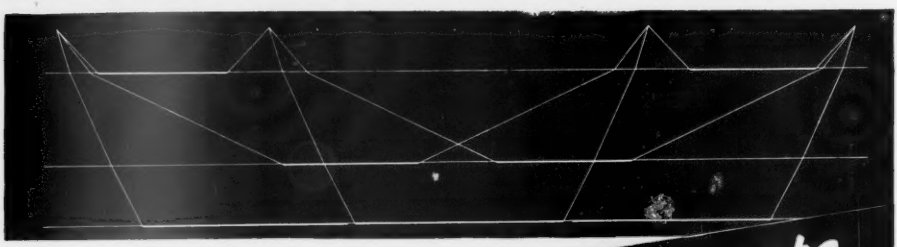

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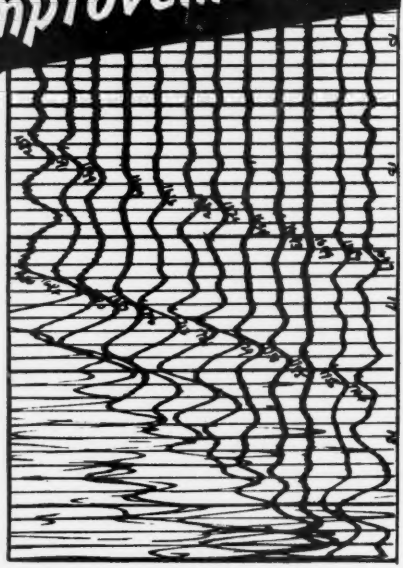

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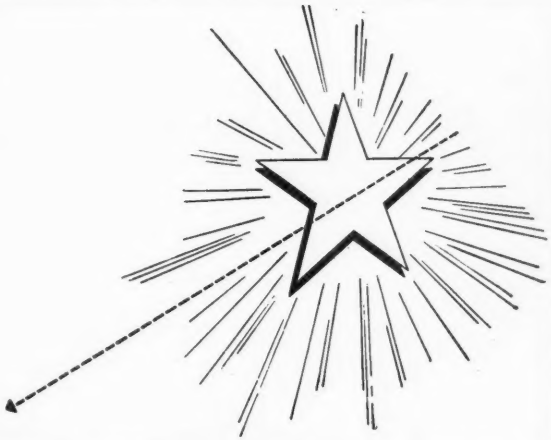

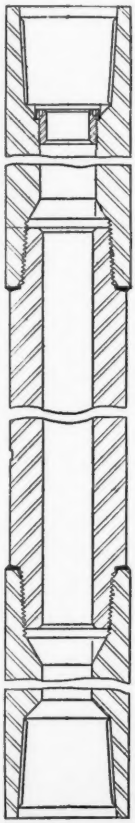

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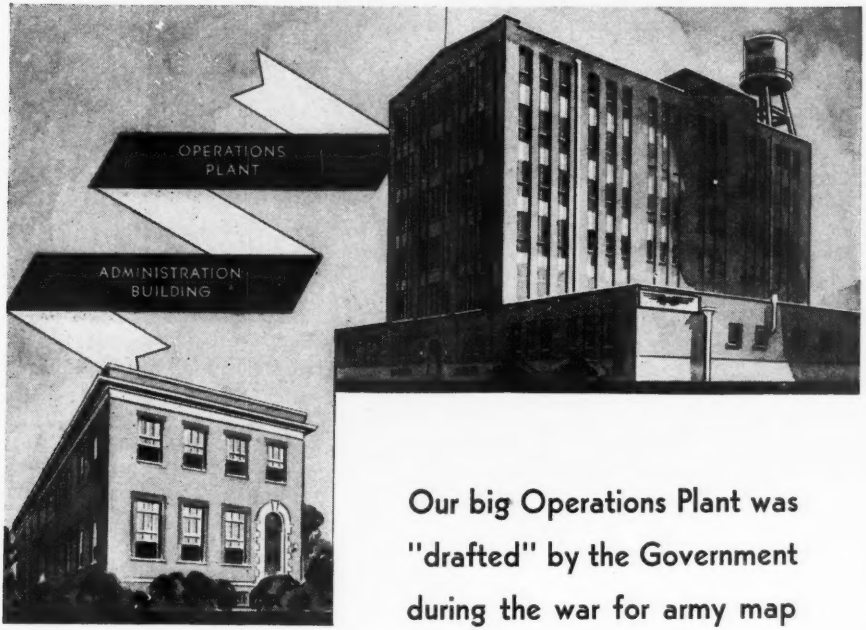

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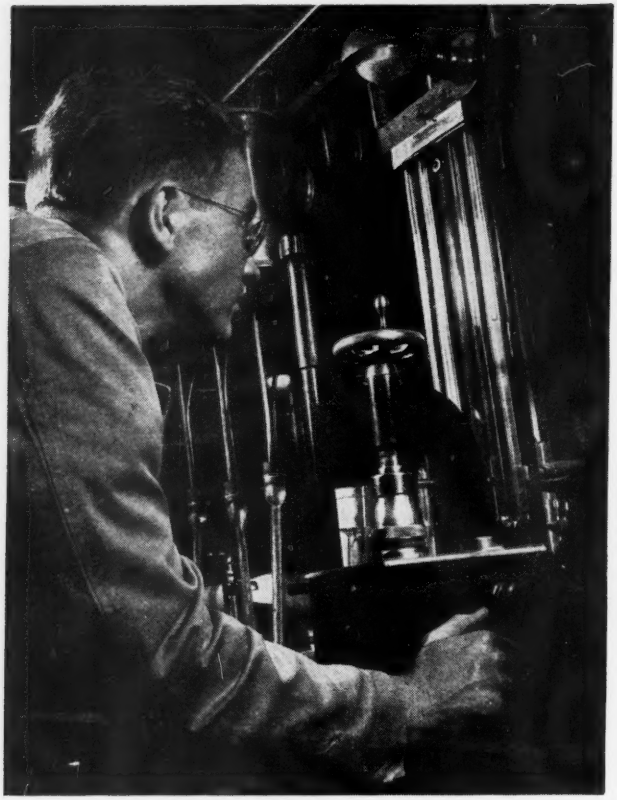

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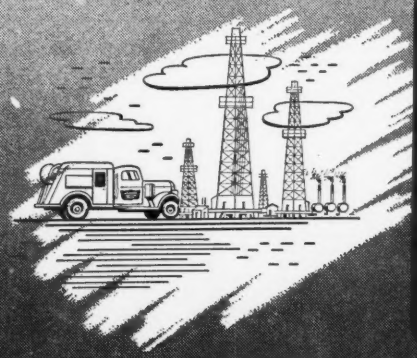

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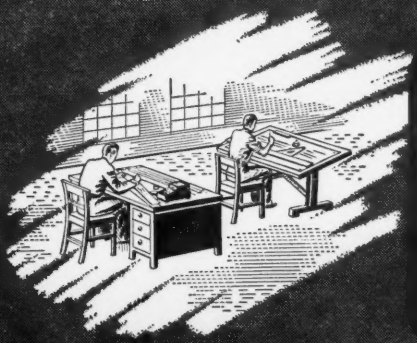

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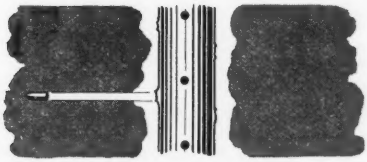

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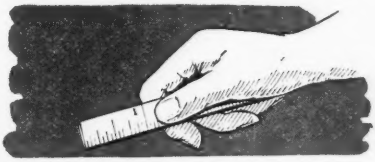

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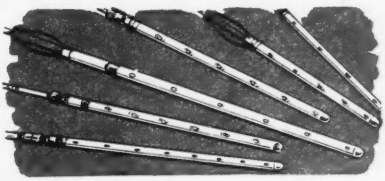

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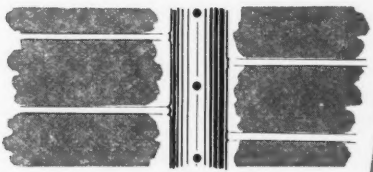

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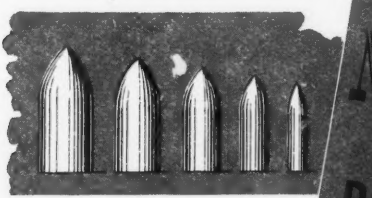

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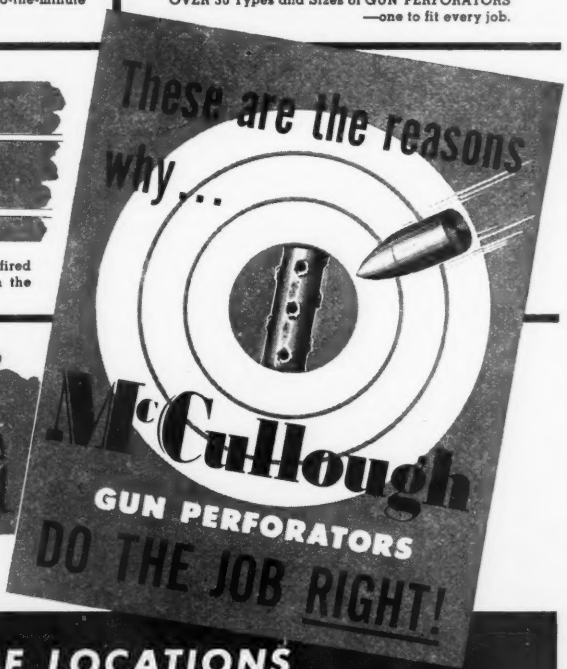

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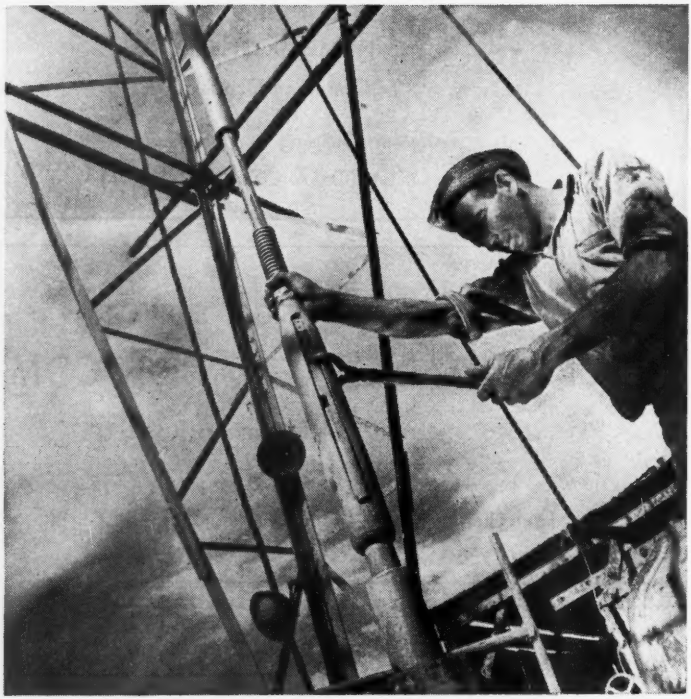

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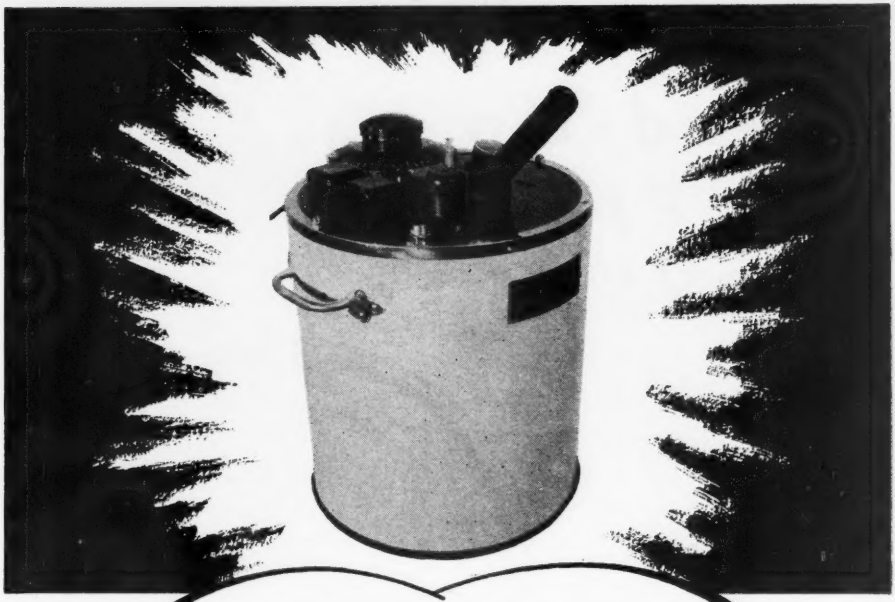

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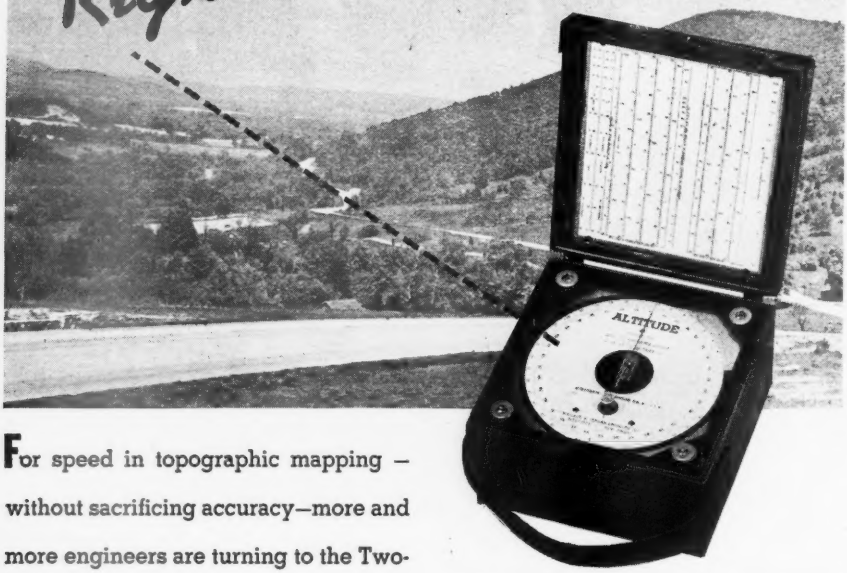

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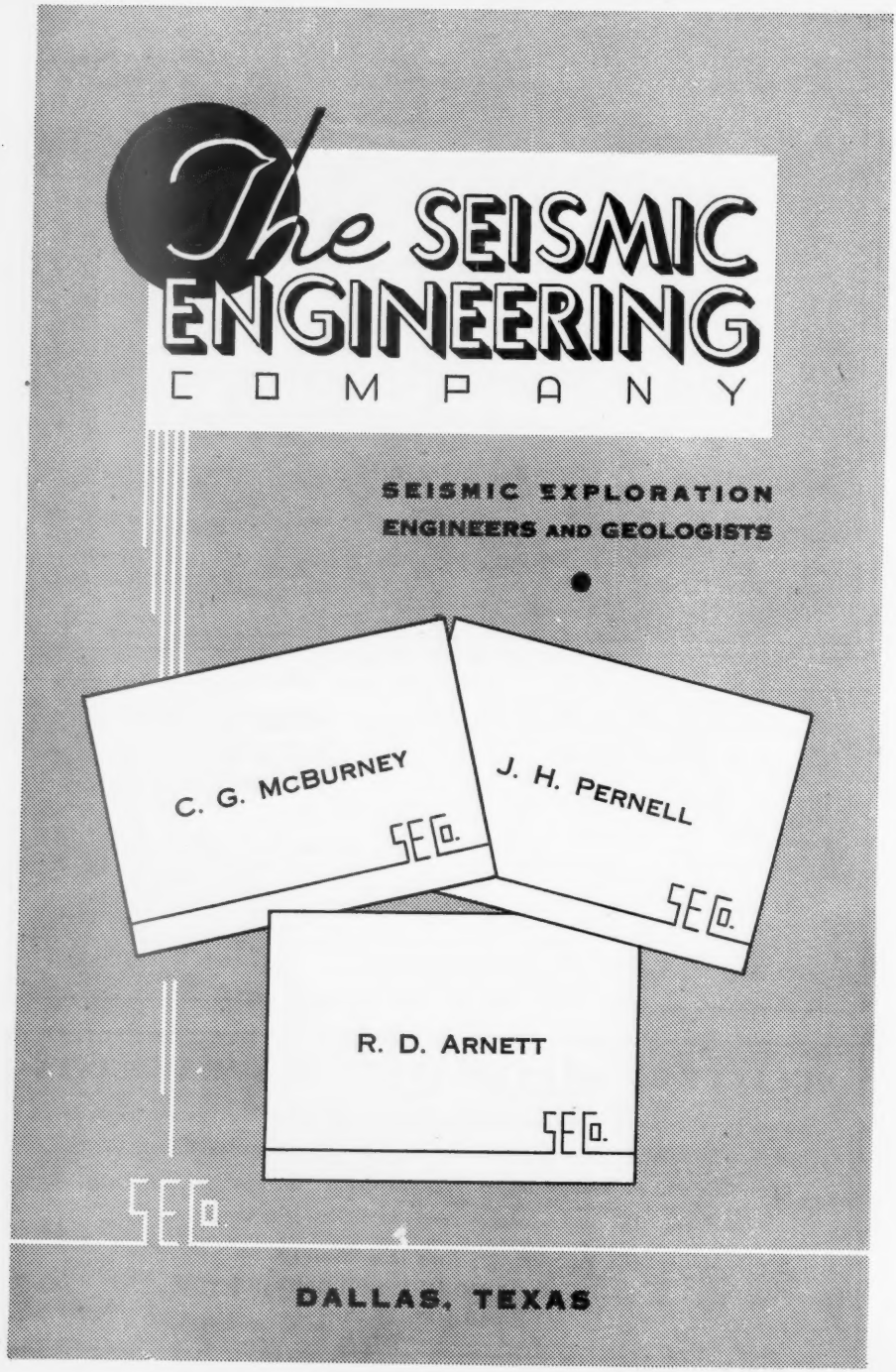
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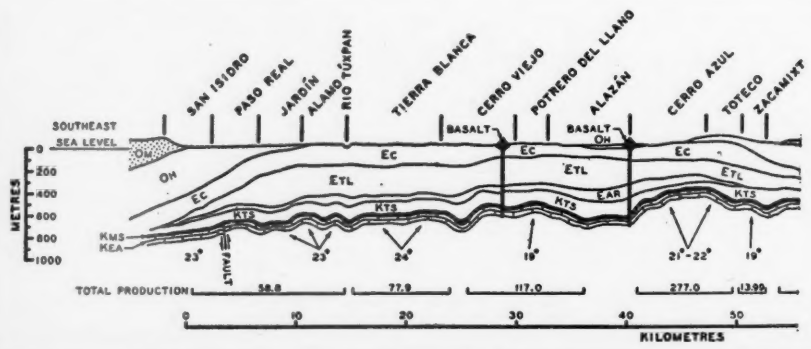

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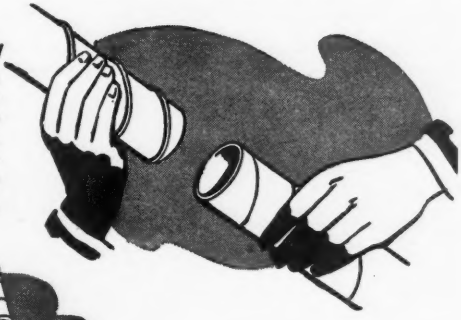

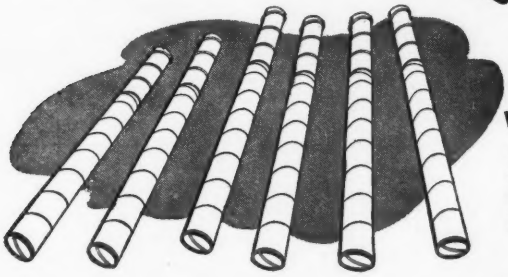

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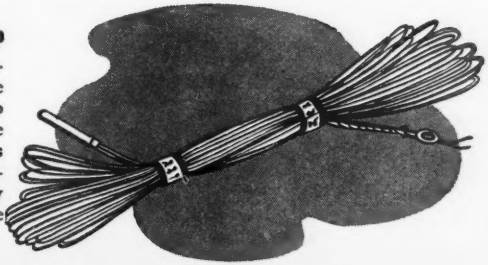

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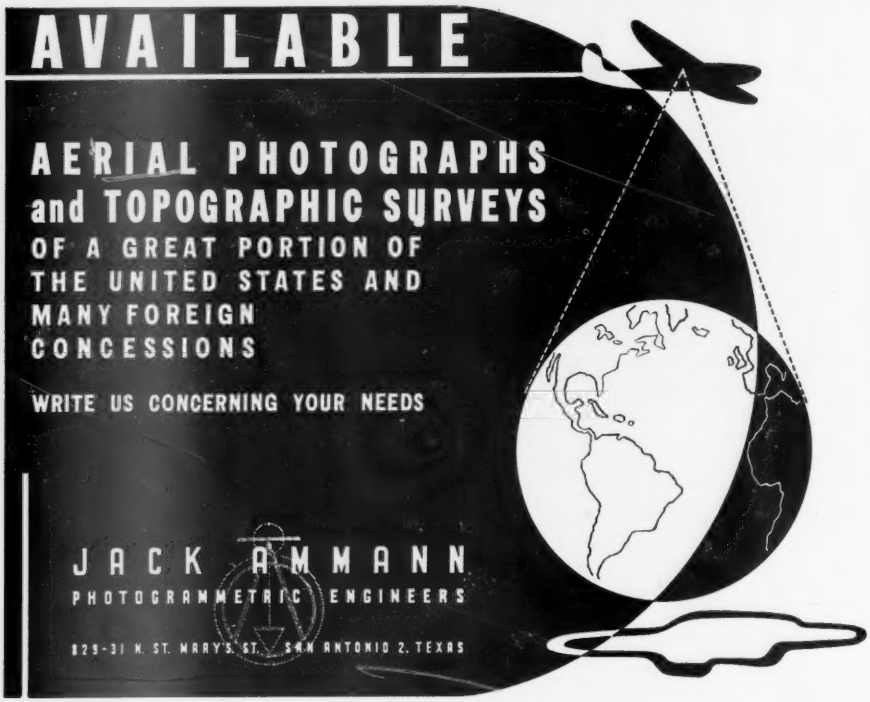

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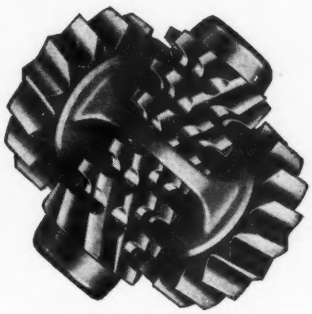

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NO. 12—129 pp. ARABIA: "Black Sea" conditions in Arabian Sea. KAN.: Permian. N. Y.: Oriskany. OKLA.: Permian. PA.: Oriskany. TEX.: Sand Hills, Crane Co.

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NO. 2—112 pp. CALIF.: Santa Monica Bay. GEN.: Repressuring; graptolites. LA.: Aragonite in salt-dome cap rocks. MICH.: Mississippian gas sands. TEX.: Aragonite. W. VA.: Oriskany series.

NO. 4—124 pp. GEN.: Appalachian field history; bibliography of structure maps and sections of oil states; folds in three dimensions. MICH.: Oil and gas.

NO. 5—116 pp. GEN.: Future of geologist; Oriskany sandstone petrology; geological limitations to oil law. N. MEX.: New section of Trinity age.

NO. 9—172 pp. APPAL.: Gas. ARABIA: Red Sea. CANADA: McMurray. GEN.: Reservoirs; 100 years ago; wildcats; secondary tilt; porosity; permeability; index determination. LA.: Shreveport. TEX.: Refugio, Segno, Cleveland pools. VENEZ.: Central.

1939 **VOL. XXIII.**—1,922 pp. 12 Nos. Each number ($1.00) 1.50

NO. 1—120 pp. CALIF.: Reef Ridge shale; Santa Maria Valley field. NEB.: Agate anticline. UTAH: "Park City" beds, Uinta Mts.

NO. 2—160 pp. LA.: Vicksburg fauna. OKLA.: Keokuk pool. TEX.: Harris Co.; heaving shale. UTAH: Washington Co.

NO. 3—180 pp. LA.: Lisbon. OKLA.: Osage. TEX.: McFadden Beach.

NO. 4—164 pp. CALIF.: Ridge Basin. LA.: Barataria Bay. MO.: Bainbridge formation. MONT.: Baker-Glendive anticline. OKLA.: Verden shoestring. TEX.: Orange field; salt erosion, Gulf. U.S.S.R.: Salt domes. WYO.: Wind River Canyon.

NO. 5—140 pp. GENERAL: Two tilts. KAN.: Greenwich pool. OKLA.: Dora pool. PERU: Agua Caliente anticline. TEX.: Travis Peak formation; Fairbanks and Satsuma fields. TURKEY: Southern.

NO. 6—218 pp. REVIEW OF DEVELOPMENTS.

NO. 7—180 pp. GEN.: Rock units. KAN.: Hugoton gas. OKLA.: Arbuckle asphalt. TEX.: Panhandle gas; Carlos structure and Ferguson Crossing, Grimes and Brazos Cos.

NO. 8—124 pp. ARK.: Basilosaurus. CALIF.: Potrero Hills gas. GEN.: Rocky Mtns.; black shale. KAN.: Loess. LA.: Stream patterns. S. DAK.: Pennington Co. TEX.: Ben Bolt and Magnolia City fields, Jim Wells Co.; Muralla field, Duval Co. TRINIDAD.

NO. 9—148 pp. GEN.: Isostatic layer; electrical logging; Gulf datum planes. ILL., IND., KY.: Coals; Salem field, Marion Co. MISS.: Jackson Eocene, TEX.: Proration.

NO. 10—164 pp. ALA.: Citronelle. CALIF.: Wasco field, Kern Co. GEN.: Oligocene-Miocene. ILL.: Basin fields; Pennsylvanian; Cambrian inlier. N. MEX.: Salado formation. TEX.: Goldsmith field, Ector Co.; Salado. WYO.: Wind River Canyon.

NO. 11—148 pp. FLA.: Everglades deep test. GEN.: Permian; marine and non-marine sediments. NEB.: Permian. N. MEX.: Castile salt, potash, anhydrite. TEX.: Gulf Coast; Amelia field, Jefferson Co.; Permian.

NO. 12—172 pp. GEN.: Drilling time; Cincinnati arch. KAN.: Permian. KY.: St. Peter; McClosky productive areas. LA.: Starks field, Calcasieu Parish.

1940 VOL. XXIV.—2,232 pp. 12 Nos. Paper. Each number.....($1.00) 1.50

NO. 1—208 pp. WEST TEXAS-NEW MEXICO SYMPOSIUM: Pre-Permian.

NO. 2—200 pp. GEN.: Permian and Carboniferous; economics; sedimentation; geophysical interpretation; Frio formation, Gulf Coast. ILL.: Chester and Iowa series. SUMATRA: Oeloe Aer fault zone.

NO. 3—208 pp. GEN.: Gulf Coast Miocene; barium in Appalachian brines. LA.: Miocene; interior salt domes. OHIO: Secondary recovery. OKLA.: Morrow group, Adair Co. TEX.: Apco structure, Pecos Co.: Sejita structure, Duval Co.

NO. 4—148 pp. ARK.: Dorcheat pool, Columbia Co. AUSTRALIA: Permian. CALIF.: Whittier Quadrangle; Kettleman Hills; Paloma field, Kern Co. COLO.: Permian. LA.: Sparta-Wilcox. MINN.: Pre-Cambrian, Cambrian. OHIO: Paleozoic, pre-Cambrian, Delaware Co. OKLA.: Osage, Washington, Nowata Cos.; deepest well, Washita Co. TEX.: Lissie and Beaumont, Gulf Coast; Sparta-Wilcox; shoreline, Brazoria Co.

NO. 5—188 pp. GEN.: Mississippian, Eastern Interior; geochemical exploration.

NO. 6—204 pp. RECENT DEVELOPMENTS.

NO. 7—196 pp. CALIF.: Rio Bravo field, Strand field, Kern Co. TEX.: Cretaceous ammonoids. WYO.: Oil-field waters.

NO. 8—176 pp. GEN.: Exploration methods; young graduates and field experience; source of hydrogen; underground gas storage. IA.: Wildcat well, Union Co. TEX.: Henderson pool. Clay Co.; K.M.A. field, Wichita Co.

NO. 9—176 pp. CANADA: Turner Valley Paleozoic limestone. CALIF.: Bakersfield Eocene coal. COLOMBIA: Jurassic-Cretaceous. GEN.: Radioactivity of rocks; GULF: Cook Mtns. N. MEX.: Caballos novaculite. TENN.: Lower Ordovician (St. Peter). VENEZUELA: Jurassic-Cretaceous. W. INDIES: Paleogene of Barbados.

NO. 10—160 pp. CALIF.: History; Eocene Yokut sandstone. GEN.: Paleontolgy. KAN.: Hugoton field porosity, permeability. TEX.: Saxet field, Nueces Co.; Rogers pool and Bonita discovery, Montague Co.; Aspermont pool, Stonewall Co.

NO. 11—204 pp. CALIF.: San Joaquin Valley Eocene. GEN.: Carbohydrates of oil and coal; unconformities and accumulation. LA.: Wilcox Eocene; Neale, Beauregard Parish. MICH.: Buckeye, Gladwin Co. MISS.: Surface. OKLA.: Ramsey, Payne Co.; Billings, Noble Co. TEX.: Wilcox Eocene; Pittsburg, Camp Co. W. VA.: Devonian.

NO. 12—164 pp. CALIF.: Miocene fishes, Torrance field. GEN.: Water cones; Permian crude. LA.: Gulf heavy minerals. MICH.: Isopach, Ellsworth-Traverse limestones. OKLA.: Structural interpretation, gravity anomalies. TEX.: Gulf heavy minerals; Hoffman field, Duval Co.; Jones Co. TRINIDAD: Los Bajos fault.

1941 VOL. XXV.—Each number.....($1.00) 1.50

NO. 4—220 pp. GEN.: Perforator samples. GULF: Crude; Midway fauna; correlation; cap rocks. KY.: Devonian. LA.: Midway; Olla, La Salle Ph. MICH.: Mississippian; Antrim-Ellsworth-Coldwater shale. OKLA.: Simpson group, Arbuckle and Wichita Mtns. TEX.: North Cowden, Ector Co.; Page, Schleicher Co.; Navarro fauna.

NO. 12—167 pp. GEN.: Shadowgraphic maps; free-oil deposition; traceslip faults; stratigraphy; radioactivity logging. N. MEX.: Sacramento Mtns. Mississipian.

1942 VOL. XXVI.—1,893 pp. 12 Nos. Paper. Each number.....($1.00) 1.50
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NO. 2—152 pp. CALIF.: Stratigraphy; Cretaceous; Del Valle field, Los Angeles Co. GEN.: Free oil accumulation. TEX.: Sewell-Eddleman area, Young Co.; Permian paleogeography; Eocene, Zapata Co.; Washburn field, La Salle Co.; McKee and Waddell sands, Simpson Ordovician, West Texas. UTAH: Laccolithic mountains, traps.

NO. 3—228 pp. CALIF.: Earthquake, Dominquez field, Los Angeles Co. GEN.: Member list; auditor's report. KAN.: Patterson pool, Kearny Co. MONT.: Madison Mississippian. N. DAK.: Stratigraphy. RUSSIA: Artinskian Permian. TEX.: Pre-Cretaceous, Edwards Plateau; Barnhart field, Reagan Co.

NO. 4—232 pp. N. MEX., TEX.: Permian.

NO. 5—204 pp. CALIF.: Sutter Buttes. COLOMBIA: Honda district. GEN.: Pseudo-abyssal sediments; salty ground waters, Atlantic and Gulf coasts; oil-field waters; annual reports. MONT.: Cedar Creek anticline. TEX.: Silurian graptolite, Crane Co.

NO. 6—216 pp. RECENT DEVELOPMENTS

NO. 7—132 pp. ARK.: Developments; Midway field, Lafayette Co. GEN.: Annual addresses; exploration; geology, war, peace; teaching; drilling-time logs; appraisals, oil reservoirs. GULF: Tertiary microfossils. LA.: Developments.

NO. 8—124 pp. COLO.: Gore area. GEN.: Discovery methods. MONT.: Oil-field water. N. DAK.: Stratigraphy. TEX.: Ellenburger; Pennsylvanian anhydrite.

NO. 9—136 pp. ARK.: Schuler field, Union County. NEB.: Cretaceous. TEX.: Well spacing, Columbia field, Brazoria Co.

NO. 10—140 pp. CALIF.: Crocker Flat, Temblor Range. COSTA RICA: Amoura shale. GEN.: Lantern-slide copy. ILL.-IA.: Pennsylvanian. ILL.-IND.: Chester sandstone; New Harmony field. LA.: Morehouse Paleozoic. N., S. DAK.: Regional. TEX.: Payton pool, Pecos and Ward Cos.

NO. 11—98 pp. GEN.: Stratigraphical analysis and environmental reconstruction. TEX.: Graptolites, Crane Co.

NO. 12—98 pp. GEN.: Engineering geology; calculating thickness; annual index.

1943 VOL. XXVII.—1,674 pp. 12 Nos. Paper. Each number.....($1.00) 1.50

NO. 3—168 pp. CALIF.: Cretaceous. GEN.: Membership; auditor's report.

NO. 4—154 pp. MEX.: Upper Jurassic. ROCKY MTNS.: Structure. TEX.: Wasson field, Yoakum and Gaines Cos.; Embar field, Andrews Co. VA.: Natural coal gas.

NO. 5—134 pp. CALIF.: Tertiary. GEN.: Annual reports. GULF: Tuscaloosa formation. KAN.-OKLA.: Desmoinesian, Missourian. MICH.: Thunder Bay Traverse rocks. S. DAK.: Rapid City water wells. TEX.: Seguin formation; Dockum conglomerates.

NO. 6—172 pp. RECENT DEVELOPMENTS.

NO. 7—152 pp. GEN.: Annual addresses; discovery thinking; geology, paleontology, geophysics, reserves, discoveries, economics, war; developments, SE. U.S.; cabletool logs.

NO. 8—136 pp. LA.: Anse La Butte, St. Martin Ph.; Jennings field, Acadia Ph. TENN.: Structure. TEX.: L. Cret. foraminifera and ostracoda; ground water at Houston.

NO. 9—112 pp. GEN.: Marine micro-organisms and petroleum; faults. TEX.: Pre-Trinity. W. VA.: Metamorphism of coal.

NO. 10—120 pp. CALIF.: Santa Maria district; Eocene, Chico Martinez area. GREAT PLAINS: Big Snowy group. OKLA.: Simpson graptolites. ROCKY MTNS.: Crude oils.

NO. 11—160 pp. GEN.: Aerial photographs. GULF: Jurassic. VA.: Deep well, Russell Co. W. VA.: Deep well, Harrison Co.

NO. 12—112 pp. CALIF.: Radiolarites, Santa Maria basin. GEN.: Chemical analysis of crudes. N. DAK.: Tertiary; Williston basin. OKLA.: Spavinaw granite. VENEZUELA: Fossils in metamorphics.

1944 VOL. XXVIII.—1,812 pp. 12 Nos. Each number.....($1.00) 1.50
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NO. 1—172 pp. GEN.: Oil in cuttings. ILL.: Bethel sandstone. KAN.: Carmi pool, Pratt Co. MISS.: Geology. TEX.: Algal reefs, Terlingua district. VENEZUELA: Anzoategui.

NO. 2—128 pp. ARK.: Schuler field, Union Co., unit-pressure; developments, 1942. GEN.: Well spacing. LA.: Developments, 1942. MICH.: Porter field, Midland Co. TEX.: West Ranch field, Jackson Co.

NO. 3—148 pp. ARK.: Developments, 1942. GEN.: Membership; audit. LA.: Developments, 1942. MEX.: Northern geology.

NO. 4—128 pp. CALIF.: Cretaceous and Paleocene, Santa Lucia Range. KY.: "Coniferous," Estill Co. LA.: Grabens; developments, 1942. TEX.: Pecan Gap, Wolfe City, and Annona formations; highest structural point; grabens.

NO. 5—124 pp. GEN.: Annual reports; velocity corrections; reserve estimates. GULF: Cotton Valley beds.

NO. 6—196 pp. RECENT DEVELOPMENTS. COLOMBIA: Free oil in ammonites. OKLA.: Viola graptolites.

NO. 7—180 pp. CALIF.: Tumey sandstone, Fresno Co.; exploratory wells. GEN.: Annual addresses: radioactivity and petroleum genesis; paleoecology, Middle Permian. MIDDLE EAST: Oil mission. MISS.: Field and salt-dome names. OHIO: Petroliferous iron ore. OKLA.: Broken Arrow coal, Rogers, Wagoner, and Tulsa Cos. TEX.: Miocene; elasticity of reservoir, E. Tex.; dolomite porosity in Devonian, W. Tex.

NO. 8—172 pp. COLOMBIA: Thrust fault. GEN.: Data on oil reserves. MEX.: Cretaceous. WYO.: Como Bluff anticline, Albany and Carbon Cos.

NO. 9—168 pp. GEN.: Stratigraphic thickness in parallel folds. GULF: Oligocene; Anahuac formation. LA.: Structure of deep domes. MO.: Bourbon High, Crawford Co.

NO. 10—144 pp. ARGENTINA: Tupungato field, Mendoza. CHINA: General geology; Red Basin, Szechuan province. E. INDIES: Sedimentary basins. GEN.: Petroleum distribution; origin and accumulation; elevations with plane table and speedometer. ILL.: Devonian subsurface; Sandoval pool, Marion Co. TEX.: Concord salt dome, Andrews Co.; fossils in Buda limestone, Denton Co.; Fullerton pool, Andrews Co.

NO. 11—112 pp. APPAL.: Underground gas storage. ARK.: Moorefield formation and Ruddell shale, Batesville district. COLOMBIA: Thrust fault. NEW MEX.: Upper Permian Ochoa series, Delaware basin. TEX.: Upper Permian Ochoa; salt diffusion in Woodbine sand; ammonoids in upper Cherry Canyon, Delaware group; South Tyler, and Sand Flat fields, Smith Co. VENEZUELA: Fusulinids, La Quinta formation.

NO. 12—140 pp. FLA.-GA.: Stratigraphy, structure. GEN.: Index; reservoir data.

1945 VOL. XXIX.—1,824 pp. 12 Nos. Each number.....($1.00) 1.50
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NO. 1—124 pp. GEN.: Radioactivity and organic content of Paleozoic shales. LA.: Natchitoches area; Midway-Wilcox of Sabine uplift; Holly field, De Soto Parish. OKLA.: Apache pool, Caddo Co. TEX.: Midway-Wilcox, Sabine uplift. VA.: Structure of SE.

NO. 2—128 pp. GEN.: Mississippian and Pennsylvanian of N. Amer.; size distribution of sand. LA.: Ruston gas field, Lincoln Parish. OKLA.: Thrust faulting, Arbuckle Mtns. TEX.: Cretaceous, Tyler basin; South Houston salt dome and oil field, Harris Co.; crystalline rocks in deep well, Winkler Co.; deep test, Moore Co.

NO. 3—160 pp. GEN.: Maddox spoon; origin of petroleum; members; financial. TEX.: Rise of water level to defective gas well, Harris Co.; Deep test, Culberson Co.

NO. 4—64 pp. ARK.: Calhoun field, Columbia Co. GEN.: Paleogeographic and palinspastic maps. MONT.: Jurassic Ellis formation. OKLA.: Graptolites, Carter Co. TEX.: Lower Ordovician and Upper Cambrian.

NO. 5—152 pp. GEN.: Annual reports; Wallace Pratt, Powers medalist; college geology students. KAN.: Ness Co. MICH.: Silurian brine, Bay City. S. AMER.: Oil possibilities.

NO. 6—228 pp. RECENT DEVELOPMENTS. TEX.: New Hope field, Franklin Co.; Bacon limestone, E. Tex.

NO. 7—208 pp. ATLANTIC COASTAL PLAIN: Subsurface. CALIF.: Upper Cretaceous in Great Valley. GEN.: Presidential addresses; middle Jurassic in Western Interior; geological calendar. MISS.: Upper Cretaceous fossils from wells. OKLA.: Graptolites, Carter Co. TEX.: Igneous rocks from deep wells. W. Tex.

NO. 8—168 pp. ALBERTA: Reservoir, Turner Valley. COLOMBIA: Petroleum geology. GEN.: Time of oil accumulation; textural standard for sample logs; research in exploration. LA.: Ground-water geology, Camp Polk. MD.: Deep test, Wicomico Co. UTAH: Mississippian and Pennsylvanian, Dry Lake, Logan Quadrangle.

NO. 9—144 pp. GEN.: Recent sedimentation and search for petroleum; vertical source in oil and gas accumulation. GULF COAST: Sedimentation. MONT.: Marine Jurassic, Sweetgrass arch. TEX.: Pre-Permian axes of deposition, W. Tex.

NO. 10—160 pp. GEN.: Radioactivity, organic content, sedimentation; photography of megafossils; research program. ORE.: Geology and oil and gas. TEX.: Subsurface Lower Cretaceous, S. Tex. WASH.: Geology and oil and gas.

NO. 11—156 pp. ALBERTA: Cretaceous of Vermilion area. COLO.: Las Animas arch, Lincoln, Cheyenne, Kiowa Cos. GEN.: Petroleum reservoirs; exploratory drilling, 1938–1944; strength of the earth. ILL.: Rosiclare-Fredonia contact, Hardin and Pope Cos. ROCKY MTNS.: Developments, 1944.

NO. 12—132 pp. GEN.: Classification of oil and gas accumulations; use of aerial photographs; Permian Word formation; surface and seismic exploration arty. TEX.: Coastal Plain Quaternary and Oakville, Cuero, and Goliad formations; Balcones, Luling, and Mexia fault zones; Pickton field, Hopkins Co.; Merigale field, Wood Co.

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NO. 1— pp. CALIF.: Los Banos district, San Joaquin Valley. E. INDIES: Oil basins; reef corals. GEN.: Hydrocarbons from fatty acids; submarine slumping; Paleozoic conodonts; classification of oil possibilities; naming multiple sands. TEX.: Waller and Harris Cos.; Devonian "pay," TXL pool, Ector Co.

NO. 2— pp. ALA.: Pre-Selma Up. Cretaceous. GEN.: Origin of continental shelves. MONT.: Jurassic-Cretaceous boundary. ORE.: Up. Nehalem River basin. PERU: SE. reconnaissance. TEX.: Katy field, Waller Co.; Low. Pennsylvanian terminology.

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